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ENVIRONMENTAL PROTECTION AGENCY

VOLUME VIII

Noise Abatement: Policy Alternatives for Transportation

The National Research Council

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ENVIRONMENTAL PROTECTION AGENCY

VOLUME VIII

Noise Abatement: Policy Alternatives for Transportation

A Report to the
U.S. Environmental Protection Agency
from the
Committee on Appraisal of Societal Consequences
of Transportation Noise Abatement

Assembly of Behavioral and Social Sciences
National Research Council

NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1977

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Foreword

This report is one of a series prepared by the National Research Council for the U.S. Environmental Protection Agency.

In June 1973 the Subcommittee on Agriculture, Environmental, and Consumer Protection of the Appropriations Committee of the U.S. House of Representatives held extensive hearings on the activities of EPA, and the ensuing appropriations bill for fiscal year 1974 directed the Agency to contract with the National Academy of Sciences for a series of analytical advisory studies (87 Stat. 482, PL 93-135). EPA and the Academy agreed upon a program that would respond to the Congressional intent by exploring two major areas: the process of acquisition and use of scientific and technical information in environmental regulatory decision making; and the analysis of selected current environmental problems. The Academy directed the National Research Council to formulate an approach to the analytical studies, and the National Research Council in turn designated the Commission on Natural Resources as the unit responsible for supervising the program.

The other studies in the series, and a diagram of the structure of the program are presented on the following pages. Each of the component studies has issued a report on its findings. Volume I of the series, *Perspectives on Technical Information for Environmental Protection*, is the report of the Steering Committee for Analytical Studies and the Commission on Natural Resources. It describes in detail the origins of the program and summarizes and comments on the more detailed findings and judgments in the other reports.

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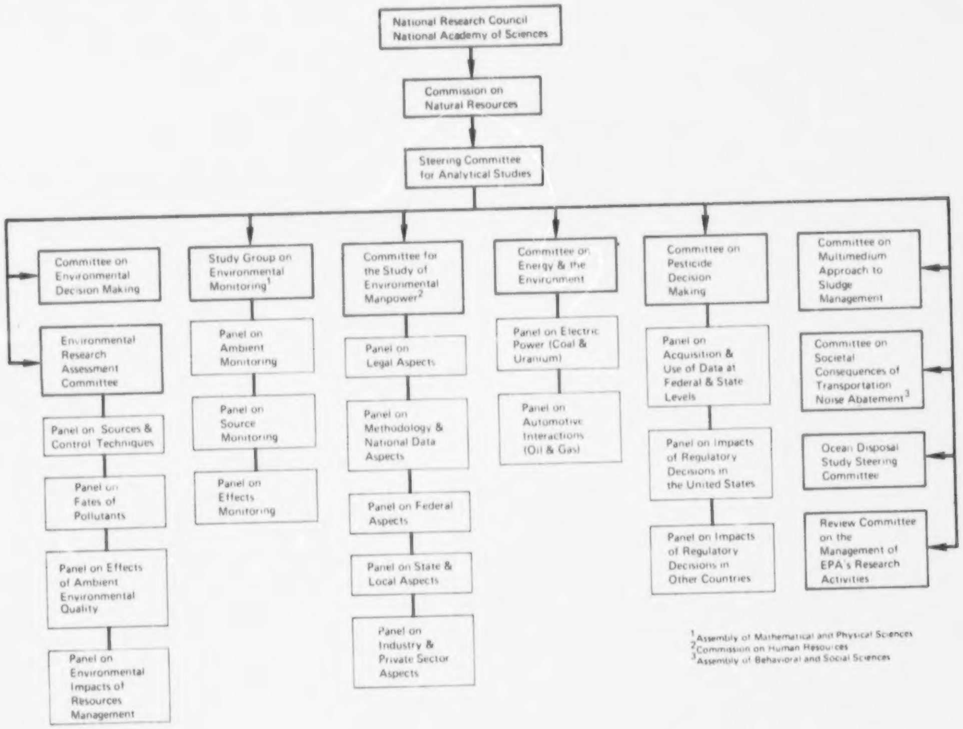
Components of the NRC Program of Analytical Studies for the U.S. Environmental Protection Agency

Project	Project Chairman	Sponsoring Unit of the NRC
Steering Committee for Analytical Studies (SCAS)	R. M. Solow	Commission on Natural Resources
Environmental Decision Making (CEDM)	J. P. Ruina	Environmental Studies Board, Committee on Public Engineering Policy
Environmental Research Assessment (ERAC)	J. M. Neuhold	Environmental Studies Board
Environmental Monitoring (SGEM)	J. W. Pratt	Committee on National Statistics, Environmental Studies Board, Numerical Data Advisory Board
Environmental Manpower (CSEM)	E. F. Gloyna	Commission on Human Resources
Energy and the Environment (CEE)	S. I. Auerbach	Board on Energy Studies
Pesticide Decision Making	W. G. Eden	Board on Agriculture and Renewable Resources, Environmental Studies Board [a]
Multimedium Approach to Municipal Sludge Management	H. O. Banks	Environmental Studies Board
Societal Consequences of Transportation Noise Abatement	W. J. Baumol	Assembly of Behavioral and Social Sciences[b]
Disposal in the Marine Environment	D. S. Gorsline	Ocean Affairs Board
Review of Management of EPA's Research Activities	R. W. Berliner	Commission on Natural Resources

[a] In cooperation with the Building Research Advisory Board.

[b] In cooperation with the Building Research Advisory Board and the Transportation Research Board.

Structure of the NRC Program of Analytical Studies for the U.S. Environmental Protection Agency


National Research Council
National Academy of Sciences
Commission on Natural Resources
Steering Committee for Analytical Studies
Committee on Environmental Decision Making
Environmental Research Assessment Committee
Panel on Sources & Control Techniques
Panel on Fates of Pollutants
Panel on Effects of Ambient Environmental Quality
Panel on Environmental Impacts of Resources Management
Study Group on Environmental Monitoring[1]
Panel on Ambient Monitoring
Panel on Source Monitoring
Panel on Effects Monitoring
Committee for the Study of Environmental Manpower[2]
Panel on Legal Aspects
Panel on Methodology & National Data Aspects
Panel on Federal Aspects
Panel on State & Local Aspects
Panel on Industry & Private Sector Aspects
Committee on Energy & the Environment
Panel on Electric Power (Coal & Uranium)
Panel on Automotive Interactions (Oil & Gas)
Committee on Pesticide Decision Making
Panel on Acquisition & Use of Data at Federal & State Levels
Panel on Impacts of Regulatory Decisions in the United States
Panel on Impacts of Regulatory Decisions in Other Countries
Committee on Multimedium Approach to Sludge Management
Committee on Societal Consequences of Transportation Noise Abatement[3]
Ocean Disposal Study Steering Committee
Review Committee on the Management of EPA's Research Activities

[1] Assembly of Mathematical and Physical Sciences
[2] Commission on Human Resources
[3] Assembly of Behavioral and Social Sciences

Preface

This report is intended to serve as an aid in the formulation of policy in the control of noise, particularly noise contributed by transportation vehicles. It is not meant to constitute a piece of original research; rather, it is intended to assemble from available information and analyses a relatively systematic and nontechnical overview that lays out the character of the problem, indicates the extent of the available knowledge and its gaps, and reviews and evaluates the instruments that can be used in formulating effective policy.

This report has been designed to satisfy the request of the Environmental Protection Agency (EPA). It is intended to assist the EPA in the formulation and execution of its own programs for the control of noise. It is hoped that it will also be helpful in the design of future legislation about noise, both at the national and local levels.

No report on noise can be truly complete; the topic is too vast for a single volume. Consequently, there are a number of subjects that the Committee does not include in its discussions.

- There is no survey of EPA's involvement in noise abatement, neither an assessment of its organization nor of its strategy in addressing the problems of noise.
- There is no attempt to survey the network of noise abatement agencies or to describe or analyze the division of labor and law among the various federal agencies, e.g., the EPA, the Occupational Safety and

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Health Administration, the Federal Aviation Administration, etc., and states, regions, and municipalities.

- The report is confined to policy issues for the United States. While it offers several references to studies in various Western European countries, it is bound to the current state of affairs in the U.S. by its premises about the legal basis for policy, the nature of the aircraft fleet, the mix and type of the automotive vehicles and trucks currently in use, and other similar factors.

As background, the report discusses the distribution of noise in the United States, the trends in noise generation and the methods of measurement of noise. It also offers a long description and assessment of the methods available for the measurement of noise abatement and provides some illustrative calculations of its benefits and costs. The report begins, however, with its central topic, the policy and legal issues in noise abatement policy.

The work of the Committee was focused on noise produced by transportation sources. There is evidence that transportation is the major source of noise in this country as measured in terms of the number of people annoyed by it, and the sound emanating from the operation of transportation vehicles has been a prime subject of regulatory concern. Nevertheless, much of our discussion is applicable also to noise emitted from other sources, and so a considerable part of our discussion is concerned with noise in general, not just with transportation noise.

Reports written by committees must all begin with individual contributions. Each of the chapters in this report was drafted or revised by particular Committee members or the study director: Chapter 2 was first prepared by Marcia Gelpe, Chapter 3 by David Green, Chapter 4 by Kenneth Eldred, Chapter 5 by Edward Morlok, Chapter 6 by Jerome Singer and William Sampson, Chapter 7 by Arthur De Vany and Jon Nelson, Chapter 8 by Kenneth Eldred and Jon Nelson, and Chapter 9 by Arthur De Vany, Jon Nelson, and Alan Walters. I tried to incorporate the Committee's overall views in the Summary and in Chapter 1.

The Committee wishes to thank members of its staff for their assistance throughout the long process of research, meetings, writing, and rewriting: Jerome Singer, the study director; Edward Friedland, senior research associate; Carol Beers, secretary; and Glenn Davis, research assistant during a summer internship. Donna Gosnell, the Committee's administrative secretary, deserves special commendation for her able shepherding of the report through to its completion. In addition, the Committee wishes to express its thanks to Eugenia Grohman, of the Assembly executive office, for her critical and incisive editing. We also wish to express our appeciation to the staff of the editorial office of the Commission on Natural Resources, Robert C. Rooney, Philippa Shepherd, and Estelle Miller, for their assistance in the production of this report.

Last, I must claim a chairman's privilege to express my deep gratitude to Dr. Singer and my colleagues on the Committee. Their knowledge and their dedication were indispensable ingredients of the process of report preparation. Above all, I enjoyed working with them and learned a great deal in the process. What more can one ask of one's colleagues?

WILLIAM BAUMOL, *Chairman*
Committee on Appraisal of
Societal Consequences of
Transportation Noise Abatement

Summary and Recommendations

The Environmental Protection Agency (EPA) estimates (1974) that 16.5 million people live in urban areas of the United States where the outdoor average sound levels are higher than those that will cause hearing loss in the long run (over a 40-year period) and that an additional 61.6 million people live in areas where the outdoor sound levels exceed those causing annoyance and interference with outdoor activities. The three major contributors to these noise levels are general urban traffic, freeway traffic, and aircraft operations. Overall, it is estimated that 75 percent of the U.S. urban and suburban population live in areas with average outdoor sound levels above or at the border of annoyance or activity interference. This is only the most obvious part of the transportation noise problem to which this report is addressed.

SUMMARY OF THE REPORT

The report is organized around two major topics: the range of alternative policy measures for transportation noise abatement and the benefits and costs of abatement. These two topics comprise Parts I and III of the report; Part II covers the measurement of noise, the current pattern of transportation noise and its effects, and the projected future pattern of transportation and the noise associated with it. The Committee's recommendations are presented in the latter part of this summary chapter.

POLICY AND LEGAL ISSUES

The Committee believes that transportation noise is a serious problem; it has health effects potentially leading to permanent hearing loss as well as significant annoyance and interference effects. A central conclusion of the Committee is that the abatement of noise requires a federal policy, but one that can be integrated with state or local programs. We also conclude that, for effectiveness and given present techniques for monitoring and enforcement, a federal abatement policy should include both direct controls and emissions charges.

Legal problems of authorization, responsibility, and mandate must be considered in policy formulation. For example, the question of whether emissions charges are to be construed as taxes, fines, or regulations is complicated and far from settled: the consequences of a judicial decision on this matter may have significant implications for the effectiveness of a program of emission charges. Since the desirability of increased reliance on a policy of emission charges is a topic of considerable concern and since so much remains to be settled about the legal status of such a policy, the discussion of the legal issues immediately follows the analysis of policy.

The choice of a particular instrument of policy for noise abatement is affected by the circumstances of the emissions. There are four types of policy instruments available: (1) direct government activities to shield people from noise or to protect them from its effects, e.g., sound insulation of schools and hospitals near airports; (2) direct controls specifying required techniques or processes, e.g., required retrofitting of muffling devices on engines or prohibition of housing construction very close to highways or airport runways; (3) direct quantitative controls, e.g., noise emission limits for trucks and motorcycles; and (4) financial incentives, e.g., subsidies for relocation of residences near airports or charges on airplane engines that are proportional to their noise levels. The report seeks to provide general answers to the questions: What determines which instruments of control should be used? At what level of severity or strength should the instruments be used?

Direct Governmental Activities

In comparison with some other areas of environmental protection, the scope for direct governmental activities in noise abatement programs seems to be relatively narrow. The government can erect sound barriers, relocate roads or runways, or build public housing in areas that are relatively less exposed to noise. But there seems to be nothing, for example, that plays the central role that waste treatment plants do in improving the quality of waterways.

Technical Specifications

Direct controls that impose technical specifications are often fairly crude and inefficient. They do not lend themselves readily to differences in circumstances, such as the differences from area to area in the ratio of residential to industrial buildings. However, this type of direct control has a significant role to play, particularly when effective monitoring is prohibitively expensive or impractical, since it is not feasible to enforce a rule that places a limit on emissions when there is no way to determine whether and by whom the rule is violated. In this case, the reasonable policy instrument is the imposition of a technical requirement, such as the installation of muffling equipment.

Quantitative Controls

Direct quantitative controls—i.e., noise emission limits—have one major advantage over technical specifications: they allow private decision makers to determine the most efficient way to comply, thus tending to reduce costs. On the other hand, as with technical specifications, this approach does not provide incentives to emitters to bring noise levels to less than the maximum permissible amount. Direct quantitative controls also require monitoring of emissions.

Financial Incentives

The last class of policy instruments consists of measures to make emitters pay in proportion to the noise emitted. By leaving it up to the emitters to choose their own ways to reduce emissions and, hence, their payments, they are motivated to reduce emissions by the most efficient means and at lowest cost. However, financial incentives, like direct quantitative controls, are practical only if effective monitoring procedures are available, to permit assessment of the appropriate payment for each emitter. It should be noted that monitoring is not always easy.

TRANSPORTATION NOISE: ITS MEASUREMENT, SOURCES, AND PROSPECTS

The measurement of noise is a complex endeavor. There are about 100 noise indices in current use, of two basic types: single-event pressure levels and cumulative measures that sum noise exposure over time. In spite of what appears to be a bewildering maze of indices, however, we find that there is a high intercorrelation between measures. Some characteristics of sound that are not well described by any index of measurement—for example, whether bursts of noise are randomly spaced or occur at periodic regular intervals—and the high intercorrelation between measures suggests that an attribute missing from one measure is not likely to be captured by any of the other measures.

The effects of transportation noise in the United States are examined in several ways in this report. First, noise from all sources is considered for the extent to which it is a source of annoyance or complaints. Transportation sources are by far those most heavily implicated by neighborhood residents: motor vehicles, for example, are cited 55 percent of the time. Second, noise sources are examined to determine the number of people affected by each and the magnitude of that effect. Noise from general urban traffic, from freeways, and from aircraft operations affect the largest numbers of people. On an energy basis, the number of kilowatt-hours per day equivalent to the noise emitted by medium and heavy trucks and by aircraft operations is 60 percent greater than the energy equivalent of 30 other common sources combined.

The projections for future transportation operations and mixture of vehicles and their associated noise production indicate that increases in transportation activities—even with each vehicle at its current noise emission level—would have only a minor effect on noise levels. The decibel scale is logarithmic, and doubling of the sound pressure level at any point results in a 3-decibel (dB) increase in sound: if a single motorcycle's noise is 80 dB, the noise from two such motorcycles is 83 dB. Thus, if all transportation activities were doubled with existing vehicles and facilities, only a 3-dB increase in general environmental noise levels would result. (It would take a 10-dB increase for the sound to be perceived as doubled). Since new vehicles, cars, trucks, and aircraft, are quieter than those they replace, it is likely that overall transportation noise will remain relatively constant, even with increased operations.

Conversely, cutting all transportation activities in half would result in only a 3-dB reduction in overall noise levels. The implication is clear that any program for abating transportation noise will have to do so by quieting sources, insulating receivers, using barriers and the like, rather than by simply reducing operations.

BENEFITS AND COSTS OF TRANSPORTATION NOISE ABATEMENT

Benefits of Noise Abatement

The report examines some of the health effects, including hearing, cardiovascular, mental health, and other health benefits of the abatement of transportation noise. The clearest and most obvious health benefit of abatement is reduction in hearing loss. While it is difficult to implicate transportation as a separate cause of hearing loss when other factors—aging and industrial and general environmental sounds—are also involved, the report concludes that a reduction in transportation noise may contribute to a significant reduction in hearing loss.

The benefits to welfare of noise abatement constitute a broader range of categories than the benefits to health. They include the economic benefits of more efficient systems, of saving resources, and of productivity increases from less noise. These occur directly when noise ceases to interfere with work and indirectly when motivation and morale are improved in a quieter workplace. The report summarizes the known effects and probable abatement benefits—and the limited information—on the social effects of noise and on annoyance and quality of life.

Monetary Measures of the Benefits of Abatement: Property-Value Analysis

While the informal weighing of benefits and costs has probably always been conducted by policy makers, the analytic economic technique of cost-benefit analysis requires that costs and benefits be described in commensurate units. Since the costs of noise abatement programs are usually estimated in monetary terms and the benefits usually are not, a model for the monetary estimation of the benefits of noise abatement is needed. The one used is based on statistical evaluation of the consequences of noise for real estate prices (the property-value model), which indicates how much individuals are willing to pay to avoid noise. The report examines the use of the property-value model in general and in a number of specific studies and also discusses a number of related issues. For example, noise at a particular location often comes from several sources—trains, cars, airplanes, etc.—but studies of particular abatement options are usually addressed to one source at a time and rarely consider their relation to the abatement options for other sources, which would be necessary to determine the cost-effectiveness of an abatement program for noise from all sources.

Costs of Noise Abatement

In considering the costs of abatement, the report concentrates on the two major contributors of noise: commercial aircraft and motor vehicles. For aircraft, such factors as the retirement rate of the current, relatively noisy fleet, the introduction of quieter new aircraft, the development of new technology, and the probable effect of increasing operations are analyzed. For motor vehicles, six categories are considered: autos, motorcycles, buses, and light, medium, and heavy trucks. For motor vehicles, factors such as production costs, fuel economy, maintenance costs, and mode of operation are analyzed.

The cost estimates are based on abatement programs involving reduction of emissions and, to a lesser extent, those involving shielding of recipients. The costs are subdivided by the degree of abatement desired and the speed with which the abatement is to be carried out. More stringent reductions in noise levels entail higher costs, and the relationship between the degree of reduction and its cost is not linear. On the contrary, the report concludes that costs accelerate as the amount of noise abatement increases.

Cost-Benefit Analysis: Some Illustrations

The report concludes with some cost-benefit calculations. These calculations do not provide any basis for evaluation of the desirability of any of the specific abatement proposals—such as retrofitting and two-segment landings—currently under discussion. Their purpose is modest—to illustrate the current state of the art and to indicate the limited degree to which they can assist the decision process.

RECOMMENDATIONS

The Committee's recommendations are grouped into five categories: emission charges and direct controls, monitoring, federal policy and coordination, research, and cost-benefit considerations. The groupings are merely for the reader's convenience and some recommendations could have been placed, equally appropriately, in a different group. Following each recommendation, the chapter that contains the supporting discussion and data is indicated. For many of the recommendations, there is pertinent information in more than one chapter; in these cases, more than one chapter is indicated, with the primary one listed first.

EMISSION CHARGES AND DIRECT CONTROLS

1. Some regulatory mechanisms are relatively self-enforcing; others require considerable enforcement activity to be effective. Provision of adequate funds and enforcement personnel is necessary for any abatement program, but is crucial if regulations of the latter type are to have anything beyond moral force. Enforcement funds adequate to assure general compliance should be provided on a continuing basis (Chapters 1, 3).

2. In the choice between direct controls and emission charges, noise abatement policy has, until now, deprived itself of what many analysts consider to be a valuable and powerful tool by its exclusive reliance on the former. If effective monitoring of the sounds emitted by an individual source is practical, the use of charges may offer substantial benefits in effectiveness, efficiency, and reliability. Accordingly, we recommend that a substantial role should be considered for emission charges in cases for which monitoring of individual sources is practical: for example, in the control of airport noise. This approach is also a promising instrument for the control of noise emitted by trucks and major construction projects, and study of the use of emission charges for the control of noise emitted by these sources should be undertaken without delay. On the other hand, largely because of the difficulty of monitoring emissions from the individual sources that contribute to the overall urban noise level and to noise along highways, it is preferable, at least in the immediate future, for programs designed to deal with these important noise problems to rely on direct controls (Chapter 1).

3. It would be highly desirable to carry out one or more carefully designed and monitored experiments to test and to document the effectiveness of a system of emission charges. This experiment should, if necessary, be authorized by explicit Congressional action and should permit the system of charges to be confined for experimental purposes (with suitable compensation, if necessary) to some limited geographic areas, say to some particular airports (Chapters 1 and 2).

MONITORING

4. The effectiveness of noise abatement programs that rely on emission charges depends on the availability of reliable and economical methods of source monitoring. Consequently, it is a matter of priority to provide means for the financing of research on practical source monitoring techniques, particularly for cases in which sound is contributed by a large

number of very mobile sources whose emissions vary with time and with mode of operation (Chapters 1 and 3).

5. Single-number noise indices (such as day-night sound level and equivalent sound level) appear to be effective in monitoring the overall noise level at a given time and location and are useful for an assessment of its effects. Once computed, however, these indices do not help in identifying the sources of individual intrusive events. As a result, some other measurement procedures will have to be used if the system of monitoring is to permit an effective set of direct controls based on source emission standards (emission quotas) or a system of emission charges; each of these regulatory procedures requires information on emissions by the individual regulated source (Chapters 3 and 1).

6. The Committee recommends that some provision be made for monitoring the effects of regulation. This includes the gathering by a central agency of current information on the enforcement of regulation at federal, state, and municipal levels as well as information on fines, emission charges, compensation awards, easement purchases, and other types of regulatory effects. This information should then be organized and made available to the public. The Committee believes that such data are essential for the evaluation of the efficacy of noise regulation and abatement policies. Publication of the results, using some medium such as the Federal Register, is recommended (Chapter 1).

FEDERAL POLICY AND COORDINATION

7. In the choice between federal policy and local option in noise control, there are grounds for favoring a federal program with as much scope for variation by geographic location as effective administration permits. Without a program designed and administered under federal supervision, there may, except in a few isolated localities, be no effective noise abatement. However, a federal program should, as far as is possible, avoid the imposition of uniform and inflexible standards that disregard local differences in needs and preferences, and it should, wherever practical, offer opportunities for genuine local choice by permitting local design of programs meeting federal regulations and subject to federal review (Chapter 1).

8. The Committee recommends that special provision be made to disseminate among local control agencies information about the design, administration, and effectiveness of various noise abatement procedures. States and municipalities are unlikely to possess the resources or personnel for research and design relating to abatement procedures. If, for example, emission charges are adopted by local governments,

considerable care will be required in structuring and in clearly explaining the charges to minimize the danger of legal difficulties. The Committee suggests that sample regulations for procedures such as emission charges, as well as techniques for monitoring, data processing, setting of rates, and the like, be distributed to state and municipal agencies (Chapter 2).

RESEARCH

9. Responsibility for research on noise is divided among several agencies, among them the Department of Transportation, the Federal Aviation Administration, and the Department of Housing and Urban Development. Since evaluation of each of their noise abatement programs depends upon the specification of each source's contribution to the total noise, we recommend that EPA, as assigned in the Noise Control Act, Section 4(c), coordinate governmental noise research. In order to specify the relevant components and to permit effective assessment of the entire set of programs, however, a mechanism for the establishment of priorities and for program control is needed (Chapter 7).

10. Although there is a large body of knowledge on the effects of noise it is, of course, by no means complete. However, the absence of definitive information on noise effects is not in itself a sufficient basis to reject a proposed regulation designed to avoid the chance of such effects. In deciding whether there is justification for intervention in an area in which there is strong reason to suspect detrimental effects, but the presence of such effects is not fully proven, one should consider both the probability that the effects will occur and the seriousness of the effects if they do occur (Chapter 6).

11. The evaluation of the benefits of transportation noise abatement programs, given the present state of knowledge, relies heavily on statistical evidence showing the effects of noise on real estate values. This is virtually the only source of systematic evidence that yields a monetary figure constituting an overall evaluation of the benefits of noise abatement that is directly commensurate with the costs of abatement. This approach is fundamentally valid, though it is subject to a number of sources of error and bias for which explicit correction must be made, to whatever extent the available evidence permits. At present, these errors are significant and reduce confidence in the results. Consequently, it is important that research be carried out to help in the design and testing of alternative or complementary methods of evaluation of the benefits of abatement, with survey research approaches perhaps constituting the most promising of these alternative methods (Chapters 7 and 6).

12. Additional research on the effects of noise on public health and

welfare will apparently cost very little relative to current expenditures on noise control and can provide significant additions to the information on which future noise policy can be based. EPA is the only federal agency that now is assigned responsibility for protection of the general public's health and welfare from the effects of noise. EPA should consequently be provided the funds needed to conduct additional research on the effects of noise on public health and welfare, with emphasis on hearing loss, other physiological effects, annoyance, and other social consequences (Chapter 6).

13. As indicated in EPA's 1972 Report to Congress (U.S. Congress, Senate, 1972), there are a number of sources of noise about whose extent, intensity, and duration little is known. If all the major sources of noise at a particular point and time were known, any proposed abatement program for one source could be evaluated after ascertaining the prior effects of all the more cost-effective alternatives for abating the other sources. We recommend investigation of the characteristics—extent, intensity, and duration—of the noise of currently unregulated sources in order to facilitate these evaluations (Chapters 7 and 8).

COST-BENEFIT CONSIDERATIONS

14. In designing programs or regulations for noise abatement, it is essential that costs be taken fully into account. At the local level, there seems to be some propensity to adopt noise control regulations regardless of the resources that must be used in carrying them out. It must never be forgotten that resources used for noise abatement become unavailable for the construction of hospitals, schools, improved housing, or for other programs of high priority for the social welfare. Costs must never be disregarded in the design of noise abatement programs (Chapter 8).

15. The Committee recommends that any evaluation of the costs and benefits of a proposal for noise abatement should explicitly consider their distributive effects. It is not sufficient to determine that, in the aggregate, benefits exceed costs or vice versa; rather, the distribution of costs and benefits among different groups must also be evaluated. The identity of the groups that will bear the cost of the abatement programs and of those that will reap their benefits is a crucial issue. An extreme example is a program that, despite a favorable benefit-cost relationship, would reduce only the noise heard by the wealthy and would levy all costs on the poor. Analyses of the distributive consequences of proposed policies sufficiently detailed to indicate possible inequities should be a part of cost-benefit analysis (Chapters 1 and 9).

16. In a benefit-cost analysis, it is not legitimate to treat the size of the

benefit-cost ratio as an index of the desirability of the program under consideration. A program with a 2.6 benefit-cost ratio is not necessarily superior to one whose benefit-cost ratio is 1.9. Rather, the appropriate criterion is the selection of a combination of programs, the discounted present value of whose expected net benefits (benefits minus costs) is as great as possible (Chapters 9 and 7).

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I POLICY AND LEGAL ISSUES

1 The Choice of Policy Instruments

INTRODUCTION

The central objective of this report is to be helpful in the design and execution of abatement policy for transportation noise. There are two fundamental issues: What is the appropriate level of severity (strength) of the abatement measures to be undertaken? What instruments of control should be used in carrying out these measures?

On the first issue there is obviously a great deal of choice. At one extreme, one could undertake absolutely no restriction of sound emissions, letting anyone produce an unlimited amount of transportation noise, without hindrance. At the other extreme, transportation noise could be reduced to zero by bringing all transportation to a standstill. Clearly, neither of these extremes is desirable or even practicable. The issue, then, is to find what intermediate point best serves the public interest.

The essence of the issue is that increased restriction of sound emission is not free. It imposes a very real cost on the community. By this we mean that the cost is not merely a matter of dollars, to which one may assign secondary importance in comparison to the effects of noise on health and human stress; rather, the costs take the form of inhibition of other vital activities. An obvious one is transportation activity itself, as has just been noted. As control of noise becomes increasingly severe, the cost of transportation can also be expected to grow, meaning that the economy will find itself paying more for this vital service and possibly obtaining

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less of it. Another cost of increased restriction of sound emissions—which is a bit less obvious but not less important—is the use of resources in the process, in building quieter engines, in insulating dwellings against noise, and so forth. All resources used in this way become unavailable for other social purposes—building hospitals and schools, eliminating slums, etc. Thus there is a real and unavoidable trade-off that is implicit in any decision to strengthen restrictions against noise.

If policy makers ignore this trade-off, they may impose a degree of reduction in noise that, while desirable in itself, imposes social costs that are greater than the gains. Or, even if a given program does produce a positive net benefit, it may be that a slightly less severe program will yield net benefits that are higher still, all effects considered. In either case, because the trade-off in terms of costs and benefits has not been considered properly, society will find its interests poorly served.

It may be noted that, characteristically in environmental programs, the terms of the trade-off become increasingly unfavorable as the program grows increasingly severe. One finds typically that, say, a 10-percent reduction in emissions can be achieved at negligible cost and a second decrease of 10 percent is apt to cost very little more, but that by the time one gets to an 85-percent reduction (in total) yet another 10-percent decrease is prohibitively expensive, while going from a 90- to a 100-percent reduction (i.e., total elimination of the emission) is for all practical purposes impossible.

In sum, because of the trade-off between costs and benefits, it is not true that a stricter (more effective) noise abatement program is always to be preferred to one that is less restrictive. The objective is to find the point at which further tightening of the restrictions is no longer beneficial from the point of view of the public interest.

In trying to help policy makers achieve that objective, this chapter examines four major questions: Is there a need for restrictive intervention? If so, what criteria should be used in deciding on the degree of noise restriction to be achieved? What role should be left to local option as against uniform national policies? (By "local" here we mean state and regional as well as municipal, strictly defined.) What instruments of control should be used: that is, what role should be played by direct controls rather than financial incentives or some other approach?

IS INTERVENTION TO REDUCE NOISE JUSTIFIED?

It has been argued that there really is no defensible justification for governmental regulation of noise. First, it can be argued that aside from outright physiological damage, the undesirability of noise is so much a matter of personal preference and cultural conditioning that the decision to require reduction in noise emissions amounts to the arbitrary imposition on others of the preferences of the group that prefers quiet. If someone likes noisy motorcycles or loud music, what right have others to require a reduction in the noise to which that person is exposed? Second, it is sometimes argued that differences in the level of noise in different areas really give people all the choice they need. If they have the necessary incomes, they can live in neighborhoods that are noisy or quiet as they prefer. Indeed, since rents and land values are reduced by noise, as has been documented amply, the market mechanism, if it is working properly, automatically provides financial compensation to those who are willing to live in noisy neighborhoods. Therefore, why is it appropriate to intervene and force people to accept noise levels lower than those they are willing to live with, in the process undoubtedly forcing their rents upward?

The answer is that, for noise, the market mechanism does not give people what they really want. There is an inherent bias in the pricing arrangements that forces people to accept levels of noise higher than they themselves would select taking into account all of the pertinent costs and benefits.

Under the market mechanism, there will be overexpansion (in terms of benefits and costs) of any activity for which the user escapes payment in whole or in part. If individuals do not pay for the water they use, for example, they tend to let taps run freely. A firm that does not pay for water will rarely if ever recirculate it if recirculation incurs any costs. The market mechanism does not work because the water-using activities impose a cost on the community, but the user of the water does not bear the full share of that cost.

Exactly the same issue arises in noise generation. Suppose, to make the argument more specific, that we can measure the social cost of noise precisely—say, that every run of a noisy truck through the center of the city causes $50 in noise damage. Obviously, it makes a great deal of difference to the economics of trucking if the firm that supplies the transportation is forced to pay that $50 or if the cost is borne by those who suffer the damage. If the truck firm is forced to pay the full cost of operation, including the $50 cost of noise damage, trucking prices will be raised, the demand for truck transportation is likely to be reduced, and the demand for substitute means of freight transportation and for quiet trucks will be stimulated. All these effects will result in a quieter city, not because someone has decided that this should be so, but because truckers must pay the costs that the noise of their activities generates. In other words, taking it to be a demonstrated fact that noise does involve some social cost, it is clear that if those who cause the cost are forced to pay for it, there will be a quieter environment.

This analysis is not undermined by the argument that individuals can now select their ambient noise level through choice of residential communities. If those who generate noise do not pay its social cost, the level of noise everywhere will be increased. Thus, with higher noise levels, even people who now live in noisy neighborhoods will generally have less quiet than they would have had otherwise. People in (the now scarcer) quiet neighborhoods will have to pay rents that are higher than they would have paid otherwise. People will pay for quiet with money they would use to pay for other things if there were less noise overall. Everyone is likely to lose in the process, except for the noise emitters who are permitted to escape the costs of their activities or the buyers of their products who also escape the social costs of their consumption. The choice of type of neighborhood in which to reside, to the extent that there really is freedom in this choice, merely permits people to divide up the burden of the excessive noise; it does not cause that excessive noise to diminish.

This standard economic analysis implies that there will be damage to the interests of society, as measured in terms of the preferences of individuals themselves, whenever those who carry out some activity do not themselves bear its costs but shift them to others. So long as the social costs of noise are not borne by those who generate it, noise levels will necessarily be excessive from the viewpoint of the affected public, and some noise abatement measures will definitely serve the public interest.

CRITERIA FOR DECIDING HOW MUCH NOISE REDUCTION IS APPROPRIATE

While it follows that some decrease in noise will generate greater benefits than costs, the critical issue for policy is the degree to which it is appropriate to restrict noise emissions. The "best" policy, by definition, involves a balancing of the benefits of noise reduction against the social costs that must be incurred in achieving these reductions. It also involves consideration of who receives the benefits and who pays the costs. Resources used in producing retrofitting devices become unavailable for the construction of schools or hospitals or housing, and this is part of the true social cost of any abatement problem. The balancing of costs and benefits of noise abatement is equivalent to the allocation of resources among competing uses, all of which offer benefits to society.

Thus, the optimal degree of noise abatement can only be decided after one determines to an acceptable degree of accuracy the magnitudes of all the pertinent costs and benefits. As the discussion in later chapters shows, the state-of-the-art is still far from the point at which it can yield clear-cut figures.

VOLUNTARY VS. INVOLUNTARY SUBJECTION TO SOUND

We can, however, enunciate several general propositions about the sorts of restrictions on noise levels that are indefensible in principle.

For this purpose, one must distinguish between voluntary and involuntary subjection to noise. A person who attends a rock concert or sits close to the tympany section of an orchestra in a performance of a Wagner opera may be subjected to higher noise levels than someone who lives 500 yards from an operating sledgehammer. But the concertgoer chooses voluntarily to be subjected to the sound level while the victim of construction noise does not.

There is a general principle that applies to this distinction: whenever all of the individuals who hear a noise choose to subject themselves to it voluntarily, the generation of that noise is deemed to cause no net social costs. That is, there is no cost that the noise generator shifts to others; one cannot use the analysis of the preceding section to argue that excessive amounts of noise will be generated.

Even in such cases, however, policy makers may decide to impose some restrictions on sound levels in order to protect those affected by it. Just as the law discourages cigarette smoking, prohibits the use of narcotics, and requires the installation of safety belts in automobiles, it may be considered appropriate to protect people from the hearing loss that frequent attendance at rock concerts may cause. But these restrictions are either (1) designed to protect society (i.e., those who do not hear the noise) from costs that the hearing of noise by the others entails (e.g., public hospital care of people who go deaf from rock concerts), or (2) they are an act of paternalism in which the government in effect decides that it knows better than the concert goers what is good for them. This applies only to choice that is purely voluntary.

PHYSIOLOGICAL AND PSYCHOLOGICAL DAMAGE VS. ANNOYANCE EFFECTS

A second distinction relevant to the appropriate level of abatement measures is the difference between noise whose effects are primarily annoying and noises that produce demonstrable physiological or psychological damage. It is not necessarily true, however, that the physiological and psychological damage must always be considered more serious and more unacceptable than annoyance. Mild and perhaps temporary hearing loss may be considered less serious than the persistence of noise that makes life extremely unpleasant, though neither physical nor psychological damage can be traced to it.

Indeed, the appropriate policy measures in the presence of either physical and psychological damage or annoyance is always a matter of balance between costs and benefits, and when all of the required information is available, exactly the same principles apply in both cases.

A significant difference may seem to arise only if facts are uncertain—potential harm has been identified but not proven. We reject the notion that the absence of evidence of more than potential harm should preclude all regulatory action. Conclusive proof cannot be expected if research is required to show that delayed effects can be attributed to earlier causes and if researchers are not allowed to conduct controlled laboratory experiments that may subject people to dangerous sound emissions. Damage that is unproven but for which there is good reason to suspect must be considered in reaching a regulatory decision, taking into account both the probability of the harm and the magnitude of the threatened damage. The larger the product of the probability and the magnitude, the greater the abatement costs it may be rational to incur. If the magnitude of the threatened damage is sufficiently large, the probability itself need not be one or very close to one in order for regulatory measures to be justified.

LACK OF THRESHOLDS FOR NOISE DAMAGE

It would be helpful, in dealing with problems of physiological damage, if there were one or more identifiable threshold levels of sound at which harmful effects to most people first become serious or become increasingly so. For example, if it could be shown that any sound less than 90 decibels produces no hearing loss but that any increase in sound level beyond 90 decibels brings with it frequent and protracted hearing loss to many people, this would immediately indicate what sound levels probably should be prohibited.

Unfortunately, the evidence indicates that matters are by no means so simple. First, since sound is multivariate in character, the damage done by sound is probably affected by pitch, duration, variability, and a number of other characteristics in addition to its intensity. Second, the magnitude of the resulting damage will vary with individuals, their age, their physical constitution, and so on. Finally, there seems to be no conclusive evidence that the damage effects of sound vary in a sequence of steps rather than increasing more or less gradually with sound energy levels. In short, the existence of convenient thresholds is, at least on the basis of the evidence currently available, doubtful at best. Accordingly, the assumption that convenient thresholds applicable to the entire population exist is likely not to be helpful in the formulation of policy and, at worst, can lead to the setting of inflexible standards whose rigidity cannot be justified by the facts.

NATIONAL CRITERIA VS. LOCAL OPTION

A third issue, which, like the others we have been discussing, affects all environmental policy, is the degree to which it is desirable to permit each community to set its own standards. Should the federal government determine goals that apply uniformly throughout the country, or should each community decide for itself the appropriate trade-off between noise and abatement cost?

In favor of local option are the significant differences in local conditions and the differences in the preferences of local populations. In the center of a densely populated metropolitan area, one simply cannot hope to achieve the degree of quiet of a remote country area. Different ethnic groups may differ in their attitude toward noise. People engaged in different activities may differ in their sensitivity to noise; a sound that is practically unnoticeable in a factory may severely disturb a hospital or a wilderness area. Moreover, even if people have the same preferences, the cost of noise abatement will cause variations in choices from one income group to another, just as it affects choice of vacation spot and type of clothing. The availability of a variety of communities that differ in levels of noise, with offsetting differences in rents and tax rates will, all other things equal, broaden the range of available choices. This, along with general distrust of an omnipotent central government, is the basic case for local control of noise emissions. There are, however, several counter arguments of comparable persuasiveness.

The first rests on a denial that there really exists the freedom of informed choice required by the preceding argument. If zoning requirements, social pressures, and a variety of other impediments effectively prevent the poor or families with small children or members of minority groups from moving into neighborhoods whose quiet/rent level combination they really prefer, then the assertion that a greater variety of situations broadens the range of choice loses its validity. The problem is compounded by lack of information about the full effects of noise. In short, lack of freedom to move may effectively undermine the broadening of choices that variation in noise levels from one community to another is said to make possible. As a result, some sort of uniformity in a national program, with all of its inflexibility, may prove to be the lesser evil.

There is a second reason for federal control of noise abatement. Competition for industry and jobs among local governments may all but prevent any effective control of noise generated by economic activities whose products are sold in a national market. Since noise abatement measures are costly, firms that operate in an area whose noise program is strong are afraid that they will find themselves at a competitive disadvantage compared to firms located in a jurisdiction whose program is weak or nonexistent. An airport whose noise standards are weak may perhaps be able to lure business from another airport with an equally convenient location but with strong abatement requirements. Any local government is afraid of driving its industry and its job opportunities into the arms of another and so none may be willing to make the first move towards the adoption of measures for the control of noise. Since each area will be reluctant to make itself unattractive to industry, if the matter is left to local option we may end up, for all practical purposes, with no abatement at all.

This problem has certainly proved a serious stumbling block for local management of controls over air and water pollution. However, the likelihood of industries fleeing from areas with strong noise measures may perhaps be smaller than in the case of air and water programs because a high proportion of noise is generated by activities that are fairly immobile. Construction and transportation may not relocate as readily as a paper mill or a chemical plant because the services provided by the former must to a considerable degree be produced in the area where they are consumed.

A third disadvantage of local control is that it may increase the cost of gathering the information needed to design a noise regulation program. Local controls require acquisition of the relevant information by all the local governments, rather than just the federal government. While some of this duplication may be avoided by having the information generated at one place and provided to agencies at other levels of government, this entails communication costs and at least some review by local governments. On the other hand, some of the requisite information may apply only to the locality in question, and here the cost to the local authority may be lower than that to a federal agency.

A fourth argument for federal regulation arises from the mobility of some major sources of transportation noise, such as large trucks and other sound emitters that move in interstate commerce. If controls on noise emissions of such sources differ from state to state, the sources will be required to comply with the controls of the strictest state. Such controls will then effectively become national controls. It may be inappropriate to have such stringent controls imposed everywhere throughout the country. In these cases, national controls may be preferable to local controls and, in any event, there may be Constitutional questions about the legal right of individual states and localities to exercise such controls.

The conclusion from all this is that the choice is by no means open and shut. Neither local option nor complete federal control is completely unobjectionable. As a compromise, one can seek the adoption of a federal program with as much flexibility built into it as effective administration can permit.

There are two ways in which flexibility can be built into a federal program. First, goals can be varied systematically on the basis of a formula that sets standards that depend on a number of variables, such as density of population, density of industrial and commercial activity, etc. Alternatively, particularly where uniformity is not crucial, the choice of criteria, perhaps within specified bounds, can be left to local option. In this case, however, it is essential that there be some attention to procedures that offer an effective voice to all residents in any area, not merely to a few groups with particular economic or political influence.

POLICY INSTRUMENTS: DIRECT CONTROLS AND FINANCIAL INCENTIVES

DIRECT CONTROLS

Most environmental programs that are now in effect use one of two types of direct control as their main policy instrument. The first type of direct control can be described as process or equipment specification: for example, the requirement that railroad tracks be welded or the prohibition of certain types of traffic in the neighborhood of hospitals. This type of direct control specifies in detail some action or process that is either prohibited or required.

The second and somewhat more flexible type of direct control can be called an assigned emission limitation or performance standard, which imposes a quantitative ceiling on emissions by any given source, leaving it to the emitters to decide how to satisfy the standard. So long as the emissions do not exceed the assigned ceiling, the emitter is taken to have complied with the regulation. (The distinction between these two types of direct control, which is significant for policy, is discussed below.)

FINANCIAL INCENTIVES

While legislators and administrators have generally shown a predilection for direct controls, most economists have argued that another approach to regulation of environmental damage is generally superior. This is the use of financial incentives in the form of emissions charges that require the generators of environmental damage to bear the social costs of their activities. The principle is straightforward: since the ability of the emitters to escape the social costs of their emissions is a central cause of activity that is socially undesirable because of its effects on the environment, the way to deal with the problem is to make those responsible for those costs bear their burden.

It should be emphasized that, as with direct controls, the basic purpose of a system of noise emission charges is reduction in noise levels, not punishment of the emitters of noise. The idea is to achieve reductions in noise by making it attractive financially for emitters to take appropriate abatement measures or, rather, by making it financially unattractive for them to fail to do so. Any payments by them or any receipts by the public treasury are incidental; a system of emission charges will be successful only if it succeeds in inducing a substantial reduction in emissions.

It should be noted that a system of charges, if set at appropriate levels, can always achieve its purpose. As an early Supreme Court stated, "The power to tax constitutes the power to destroy . . . ." Emissions charges are not taxes, and it is not their object to destroy any economic activities, but a non-token charge can always be set at a level that achieves whatever degree of noise abatement is desired. The issue is not whether a system of charges can reduce noise, but whether they are in any circumstances the most effective way to do the job.

The levels of such charges can be determined in one of two ways: they can be made equal to the best available estimate of the monetary value of the social damage caused by a unit increase in emissions (which, if satisfactory information is available, is considered by economists to be the best approach); or they can be formulated in terms of a set of target standards for source emissions or environmental sound level, with the charges selected, on the basis of the statistical evidence, sufficiently high to induce the reductions in emissions necessary to achieve those standards. These target standards can be determined either on the basis of some evidence of harm or on the basis of some evaluation of the requirements of effective control.

It should be noted that, to be effective, a system of charges must apply to governmental as well as to private emitters. If the truck fleet run by a state or a federal agency is responsible for unacceptable amounts of noise, an appropriate payment should be taken from its budget as an inducement to take appropriate abatement measures. Exemption of any class of emitters from any type of environmental program is obviously likely to impede its effectiveness and efficiency although there is neither a legal nor a logical barrier to the establishment of an emissions charge plan with one or more classes of emitters excluded.

THE CHOICE BETWEEN DIRECT CONTROLS AND FINANCIAL INCENTIVES

The authors of this report take a position intermediate between the two views that direct controls should never be used and the belief that they are the solution to all noise problems. We conclude that policy makers have gone much too far in the universality of their rejection of financial incentives and have denied themselves a set of potentially powerful and efficient tools that can make valuable contributions to environmental policy. On the other hand, a large number and variety of emissions, particularly in the case of noise, are best dealt with by direct controls rather than by emissions charges, at least given the present state of knowledge and technology. In the remainder of this chapter we will discuss the virtues of each of these basic approaches and suggest in broad terms which types of sources of noise are best controlled by which method.

In confining our discussion to the three types of instruments—the two types of direct control and the use of charges for noise emissions as a financial inducement for abatement, we do not intend to imply that these are the only instruments that have been proposed or discussed. A variety of other tools, such as subsidies for insulation or construction of sound barriers and the auctioning of sound emission permits, have also been used or suggested. However, we believe that in practice the major contenders for a primary role in noise abatement policy are the instruments discussed here, and we will therefore do no more than refer to the other policy instruments.

Desirable Attributes of Emission Charges

The grounds on which economists have argued the superiority of a system of charges for environmental damage over reliance on direct regulation and enforcement through resort to the judicial system for fines or orders in each individual case have been presented so often that a brief summary will suffice for this report. First, economic incentives in the form of charges for environmental damage will prove more effective in both the long run and the short. Although they are not, legally speaking, a tax and are not collected through the tax system, charges will be collected on a regular basis just as taxes are. Of course, resort to the courts will be necessary to compel payment by those who do not comply with the system, so enforcement can at least initially turn out to be as burdensome as enforcement under direct controls, though it is hard to believe that it will continue to be so once the charges have been tested in the courts and have become routine.

Second, emission charges (like taxes), once effectively in operation, tend to be self perpetuating. Direct control systems depend more on repeated initiation of enforcement actions by the regulator. Therefore, a charge system should continue to work even if an environmental issue disappears temporarily from the headlines.

Third, economists believe that a system of emission charges promotes efficiency in an environmental program. That is, it induces a pattern of abatement by individual emitters who comply with a program that improves the environment at as low a cost as is practicably achievable. It provides the largest financial incentive for abatement measures to those emitters who can abate most cheaply and efficiently and can therefore avoid the charge at lowest cost to themselves. This contrasts with most programs of direct controls, which usually try to apportion the task of abatement among emitters in a manner that is considered fair, rather than attempting to assign them on the basis of the relative costs of the abatement measures by different emitters.

Fourth, regulation through a system of charges for environmental damage involves minimal interference in the freedom of choice of individuals, not dictating how they must operate or what technical processes they must adopt. Rather, it uses the price system to stimulate their effort and ingenuity to achieve the objective of environmental protection. This also avoids locking firms into one technology dictated by regulation, which may later prove to be inefficient for particular firms or plants.

Fifth, and perhaps most important, a program of charges does not transform normal economic behavior into a matter to be dealt with by criminal penalties. Although high levels of noise emission may be dangerous, there is nothing inherently criminal about them. Rather, it is a part of everyday economic activity, which may, however, involve a misuse of society's resources. Just as a trucking firm is expected to pay for its labor and its fuel, it is appropriate for it to pay for the insulation and medical costs its activity imposes on others. Emission charges force manufacturers to take cognizance of the social cost of their products (and emissions) along with the cost of production.

Sixth, a system of emission charges can potentially provide some revenue to the government and hence perhaps reduce to some degree its need to raise revenue by other means. This is in marked contrast to other instruments of noise control policy, which generally require substantial increases in government expenditures. However, this point should not be overemphasized. Emission charges are not intended as a revenue-raising device, and to the extent that they are successful in reducing noise emissions, the payment of charges by emitters will be reduced.

Two other issues about a system of emissions charges require comment. It is often asked whether such payments by emitters will ultimately fall proportionately more heavily on the rich or the poor. The answer is that no one really knows. For example, it may be surmised that if emission charges were paid by airlines, the bulk of the cost would be borne by rich people, who fly more often than poor people. But part of the cost would be borne by air freight, which may or may not involve products bought preponderantly by more affluent consumers, and part of the cost may be covered by lower wages for airlines' cleaning personnel. In short, many of the ramifications are so indirect and remote that we cannot say with any degree of confidence who is likely to end up paying the largest proportion of emissions charges. What spotty evidence there is constitutes some reason for concern that the poor may indeed pay more than their share (see, for example, Freeman 1972, Dorfman 1975, 1976, and Baumol and Oates[1]) but this may well be as true of the costs of environmental programs involving direct controls.

A second question relating to a system of emission charges is whether it will work in view of the apparent ability of the emitters simply to pass the charges on to consumers in the form of higher prices and go on emitting. The answer is that, except where the firm in question is completely removed from competitive pressures, it cannot pass all of these charges on to its consumers. The most conclusive evidence that this is so is the virtually universal and bitter opposition of emitters to a system of charges, an opposition that can most readily be explained by the fact that these charges will cost them some money.

It is of course true that the charges can be expected to produce some rise in the prices of the emitters' products. But this, too, is part of the abatement mechanism of a program of financial incentives. For the rise of relative prices of commodities that cause emissions will help to shift consumer demand toward commodities whose production is less damaging to the environment, and that, surely, is one of the aims of such a program.

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[1] Baumol, W.J. and W.E. Oates: Economics, Environment and the Quality of Life. Englewood Cliffs, NJ: Prentice-Hall, Inc., forthcoming.

Circumstances Favoring the Use of Direct Controls

Despite the arguments for the virtues of a system of emission charges or financial incentives, they do not constitute a panacea for all environmental problems. There are many circumstances, perhaps encompassing the preponderance of major sources of noise, in which emission charges will prove impractical or not be as effective as direct controls. Specifically, there are at least six general cases that favor direct controls. In four of them, direct controls are inherently superior, while the other two are matters of adaptation to political and institutional realities.

First, if the effects of an emission are judged to be so serious that it should be prohibited altogether, then there is clearly nothing to be gained by setting up the elaborate machinery involved in imposing charges that would have to be so prohibitively high that they would never be collected. While it is true that charges can, in principle, work even in these cases, there is little point in using this indirect route. It is not clear that this advantage of direct controls is likely to be of major significance for noise abatement, except perhaps for the protection of workers in extremely noisy factories or the prohibition of operations by particularly noisy aircraft.

Second, if there is a likelihood of unanticipated environmental emergencies, particularly if their consequences are extremely serious, a system of charges may prove to require too much time for its adoption or modification and be too slow in eliciting its effects. When there is an air pollution emergency that threatens to cause an unacceptable increase in both mortality and morbidity, the easiest and most effective policy approach may be a ban on the use of private passenger vehicles except for emergency purposes and a ban on the use of incinerators (perhaps with certain specified exceptions). This may not be a case that is important for noise abatement since it is hard to imagine serious and unanticipated noise emergencies. Physiological damage from noise is usually a result of protracted and repeated exposure to sound; hence, the fact that direct controls lend themselves to modification on short notice seems to offer little or no advantage in noise abatement.

Third, and probably the most important case in which direct noise abatement controls offer advantages over financial inducements, is if monitoring of emitting sources is impractical because it is unacceptably inaccurate or costly; a program of charges will not work if it lacks the information on which to base its assessment of fees. Charges that are only haphazardly related to individual emission levels will fail in their basic objective—the provision of a reward (the reduction in payments) that increases with every reduction in emission levels.

It is important to note that where monitoring is impractical, the assigned emissions limitation (performance standards) approach to direct control is ruled out as effectively as a program of emission charges. One cannot enforce a fixed maximum decibel level on motorcycles if one has no way of measuring how much noise any given motorcycle emits once it leaves the showroom. Where effective monitoring is not practical, process or equipment specification (such as required retrofitting or welding of rails) remains the only reasonable option.

After reviewing the available material on noise monitoring techniques, we conclude that some sources can be monitored with sufficient effectiveness and economy to constitute no significant impediment to the use of charges as an implement of regulation. In other cases, source monitoring is far more difficult, and direct controls of the equipment-specification type may be the only available option.

The level of noise emission of standardized commercial vehicles, such as aircraft or trucks, can be evaluated in different circumstances by testing of the prototype model or by periodic retesting, vehicle by vehicle, although both of these approaches may run into some legal problems. While the character of their noise emissions will vary with speed and route, sample studies and records may provide tolerably approximate information. Strategically placed microphones at construction sites or along railroad tracks may be able to provide most of the information that can reasonably be desired for a program of charges, though there are some techniques for partial evasion of such monitoring procedures. Small construction projects of short duration and general highway and urban noise levels, however, constitute difficult monitoring problems, and, taken together, are major sources of noise emission.

Fourth, financial incentives work very imperfectly if there are ways the emitter can escape the burden of charges. This may be true of emissions generated by government activity unless the charges cut directly into the budget of the agency that operates the vehicles. If political arrangements permit the agency to increase the budget by an amount sufficient to cover the charges, its motivation will be undermined, and only direct controls will be able to induce an improvement in performance.

The same may be true, at least partly, of a regulated public utility in private industry, such as an airline whose profits are effectively constrained, if it is permitted to raise its prices to cover any emission charges. There are two important reservations here: first, regulatory lag is likely to delay any such price adjustment and, meanwhile, the burden of the charges will fall on the emitter. Perhaps more important, any rise in prices granted by the regulator will discourage consumption of the emitting products to some degree and will reduce emissions correspondingly. In any event, it is clear that, in either of these circumstances, the case for a program of financial inducements is weaker than it is when more of the burden of these charges falls on the emitter.

Fifth, in light of the legal issues (see next chapter), it is possible that a program of emission charges will initially involve more complex, costly, and time-consuming challenges in the courts than a program of direct controls. If so, this should be counted as an item that favors the latter. However, it is by no means clear that matters work out that way on balance. Experiences such as the Reserve Mining case, which has so far been in the courts for seven years, indicate that direct controls are by no means immune from legal costs and delays.[2]

Finally, it is no doubt true that direct controls are today more acceptable politically than are emissions charges. One may conclude that, even if charges are otherwise superior, it is better to settle for the second-best program of direct controls than to hold out for the best and end up with none at all. We are not in a position to judge this matter. We may conjecture that the opposition to emission charges by local governments may weaken if their financial difficulties continue to grow (as there is good reason to expect), for a program of direct controls is likely to add costs for enforcement while a system of charges will, incidentally, provide additional revenue.

TOWARD A CHOICE OF POLICY INSTRUMENTS FOR NOISE ABATEMENT

As we have seen, monitoring is one of the key considerations affecting the choice among the three major options: direct controls by process or equipment specification, direct controls by assigned emission limits, and emission charges. If monitoring of emissions by individual sources is cheap, accurate, and effective, there is a great deal to be said for the use of emission charges, while if effective source monitoring is impractical, only process or equipment specification will work. This suggests that the approach that most nearly resembles a compromise—direct controls by assignment of quantitative emission limitations on individual emitters—

[2] The Reserve Mining Company, jointly owned by Republic Steel and Armco Steel, dumps tons of taconite tailings (asbestos-containing wastes) into Lake Superior, a chief source of drinking water for Duluth, Minnesota, and many other communities. The grave health effects of the ingestion of asbestos fibers appear to be well documented, but the courts have been unable, in seven years of litigation, to ban the dumping of these wastes.

may rarely be the preferable choice. Either the more extreme form of direct control or the use of financial incentives is likely to be superior.

There is, however, a second form of intermediate arrangement. This is the use of financial incentives along with assigned emission limitations, which the emitter is prohibited from exceeding in any event. If charges are sufficiently high to be effective, the limitations are likely to serve merely as standby ceilings that are in fact rarely, if ever, reached. Nevertheless, such an arrangement may prove comforting to those who are skeptical about the reliability of financial incentives.

On the critical issue of monitoring, we may note that noise abatement programs differ in two significant ways from other environmental programs. First, despite its many problems (discussed in later chapters), noise monitoring is probably more accurate, more straightforward, and more easily automated than monitoring for almost any other major emission. This would appear to suggest that a system of emission charges would be particularly promising for noise control. Commercial jet aircraft are probably the best candidates for emission charges since they operate from a small set of airports and are capable of being monitored with sufficient accuracy. However, in many cases of urban or highway noise, the sound is contributed by a very large number of highly mobile sources. It is extremely difficult in such cases, despite the effectiveness of monitoring equipment, to attribute a specific component of the total sound to a particular automobile, truck, or motorcycle. While in such situations it is possible to monitor the general level of environmental noise quite accurately, and even, perhaps, to distinguish the contribution of particular classes of emitters (truck tires versus motorcycles), it is hard to determine, for example, which vehicle muffler was defective and how much it contributed to the overall noise; this would be required by an effective program of emissions charges. All these considerations are reflected in our recommendations on appropriate instruments of control.

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2 Legal Issues

INTRODUCTION

This chapter examines some legal issues that must be faced in deciding how (and whether) to impose governmental control on transportation noise. Legal issues must be considered so that the legal protection to various parties is provided while unnecessary legal challenges are avoided. The chapter deals with a few of the legal issues affecting noise regulation, focusing on problems that have received only limited attention in the past and that are particularly relevant to the findings discussed in this report.

First, it considers the legal problems raised by emission charges as distinct from other forms of governmental regulation of noise. While this type of regulation is emphasized by economists, it has received very little judicial consideration. While economists have frequently compared emission charges to taxes, this is not a felicitous comparison from the legal point of view. That is, if the courts treat emission charges as taxes, they are likely to find them invalid. Furthermore, if emission charges are treated as criminal penalties, the charge system will be so burdened by procedural requirements that the advantages posited for a charge system will be lost. The most advantageous legal characterization of emission charges would be as some sort of civil fine or, better yet, as a unique regulatory device.

Second, the chapter considers legal problems that are raised by regulation that is designed primarily to prevent annoyance, nuisance, etc., so-called aesthetic harm. Most people dislike noise—that is, they view noise as an aesthetic harm—so aesthetic objections are clearly identifiable as a reason for noise regulation. While we know of no past examples of federal regulation explicitly designed to prevent aesthetic harm, we believe the federal government should be able to regulate for aesthetic purposes. It should be noted that the power of state and local governments to regulate on aesthetic grounds is firmly established.

Any regulatory scheme involves a myriad of legal problems. These are generally familiar to lawyers versed in administrative law and are not included in this chapter, which is not designed as a definitive legal study. It is intended more modestly to highlight a few legal issues that may have a significant effect on shaping the regulation of transportation noise and on which information is not readily available.

A SYSTEM OF EMISSION CHARGES

We begin with a description of how a system of emission charges might work.

An administrative agency would set a schedule of charges after considering the levels and effects of noise emissions from the noise sources or categories of sources to be subject to the charges. The charges could be set in several different ways. The charge on any given noise emission could be related to the value of the harm caused by that level of emission: the charge could be made equal to the best available estimate of the monetary value of the damage caused by the noise. Alternatively, a generally acceptable level of noise could be determined. (This would not have to be a level at which there is no harm from the noise, but rather a level at which the harm would be accepted without charging any costs to the noise emitter.) A charge could then be made for noise emissions in excess of that level. The charge for any increase in emissions would be an amount equal to the incremental cost of the harm caused by the emission increase. Charges set in either of these manners are harm-related charges. Charges can also be set on a control-related basis. An acceptable base level of noise emissions would be determined, and charges for any emissions in excess of that level would be set at a level sufficiently high to induce a reduction in emissions to the base level.

Notice of the charge schedules would be given to emitters, who would have an opportunity to challenge them before the agency and the courts. Once the schedules were settled, the agency would make periodic determinations of emission levels from each source or category of sources, and charges would be assessed based on those levels and the charge schedules. Before any emitter could be required to pay the assessed charge, it would have an opportunity to challenge the assessment either before the agency or before a court.

For example, if the agency found that the emissions from a certain type of truck were 95 dB(A) (decibels, A-weighted sound level, see Chapter 3), and a truck fleet owner claimed that they were only 85 dB(A), the owner would be able to challenge the agency finding. The challenge might be brought before a court or the administrative agency. If it were brought before the administrative agency, it would be subject to limited review by a court. In either case, if the challenge were unsuccessful, the emitter would have to pay the assessment. The agency could seek the aid of a court to compel payment, if necessary.

LEGAL CONSTRAINTS ON A SYSTEM OF EMISSION CHARGES

There is no true system of emission charges now in operation in the United States. If a system of emission charges for noise regulation is instituted, courts will probably have to determine whether the charges are valid and what legal limitations apply to them. In making this determination, courts may view emission charges as a unique and new type of regulatory device, or they may treat them as analogous to existing types of monetary assessments, applying to emission charges those legal rules that apply to such other assessments. Statements of legislatures and administrative agencies may guide, but they will not bind the courts in deciding how to characterize emission charges.

This section surveys the other devices that emission charges may be taken to resemble and the legal constraints on their use that would follow. It also discusses whether specific statutory authorization for emission charges, as distinct from other types of regulatory programs, is required before emission charges may be imposed by a regulatory agency.

Taxes

Perhaps the most familiar type of government assessment is a tax. It is difficult to define a tax in a way that distinguishes it from a license fee, a fine, or other monetary assessments. The best we can say here is that a tax is a type of revenue-raising device to which a certain set of legal constraints usually applies. If emission charges are treated as taxes, these constraints would apply to the charges and may limit their usefulness. There would at least be some uncertainty about how the charges could be set and applied.

One of these uncertainties is whether an administrative agency would be permitted to set a tax. The system of separation of powers prohibits a legislature from delegating too much power to an administrative agency, which is part of the executive branch of government. A statute delegating so much power to an agency that it violates the separation of powers doctrine would be held invalid by a court, and the regulations passed under such a statute would also be invalid. While federal courts in recent decades have not invalidated statutes on delegation grounds, a recent case (*National Cable Television Association, Inc.* v. *United States* 1974) suggests that the threat to a statute is still alive when the power to tax is concerned. According to this case, a statute may be invalid if it delegates to an agency the power to set taxes without sufficient guidelines on how that power must be exercised. The cable television case may be read to suggest that an agency cannot be given the power to set taxes at all (but see *Federal Energy Administration* v. *Algonquin SNG, Inc.* 1976). A similar doctrine is recognized by some states. In fact, some state courts may apply the doctrine against emission charges even if federal courts do not do so. If so, federal agencies could set emission charges, but state agencies in some states would not be permitted to do so.

This could be a significant impediment to use of emission charges, because it is desirable to have an agency rather than a legislature set such charges. Setting emission charges involves many technical determinations about medicine, economics, sociology, geography, etc., and agencies are generally more adept than legislatures at handling complex technical problems. Moreover, agencies are more likely than legislatures to have the flexibility needed to adapt to unforeseen problems in designing a new type of system. In addition, charges will probably vary over time as a result of changes in prices, in the volume of total emitter activity, in control technology, etc., and legislatures are less well suited than agencies to monitor such changes and to adjust charges to them. If the setting of emission charges by an agency is held invalid on delegation grounds, the advantages of expertise and flexibility may be lost. Since the delegation problem is more likely to arise if the charges are characterized as taxes, such a characterization would be unfortunate.

One way to minimize a potential delegation problem would be to have the legislature specify in a statute what factors the agency must consider in setting charges. Alternatively, the delegation problem would be circumvented were an agency to recommend charges to the legislature, with such charges then enacted by statute. But this technique is likely to be ponderous, particularly at anything other than the local level. In addition, it is more likely to produce charges set in part on the basis of particular political trade-offs that are beyond, and even contrary to, the economic rationale for the charges.

Emission charges, if construed as taxes, would be a form of indirect taxes. Indirect taxes levied by the federal government must be uniform throughout the United States. Similarly, in most states, taxes levied by the state must be uniform throughout that state. Under certain conditions, some differences in tax rates may not violate the uniformity requirement: similar activities must be taxed at the same rate wherever they are found, but activities that are deemed different may be subjected to different rates. Thus, emitters of different levels or kinds of noise could be charged at different rates. However, it is unclear whether one emitter of a given noise could be charged more than another emitter of the same noise just because the first emitter is located in a more populous area where there are more hearers and greater external costs associated with the noise emissions. Yet the economic rationale for harm-related emission charges that the charge be set at the level of the external cost associated with the emissions—would require that higher charges be assessed to the emitter in the more populous area. (Similarly, it is unclear whether equal emitters could be charged different amounts because of different control costs; this may be desirable under a control-related charge scheme.)

A federal system of emission charges construed as taxes may face a further problem. State and local governments are immune from federal taxation under certain circumstances. This immunity from taxation may be more extensive than state and local immunity from direct federal regulation. Thus, if emission charges are characterized as taxes, it might be difficult for the federal government to apply the charges to state and local governments. However, the tax immunity does not now appear to be very broad, and even if emission charges are construed as taxes, they probably could be assessed against states and localities as long as they neither discriminate against states and localities as noise emitters nor unduly interfere with the sovereign functions of the taxed governments. These rules would probably permit the federal government to apply emission charges to most state-owned vehicles even if the courts chose to treat the charges as taxes, although some immunity question may arise if almost all of the types of vehicles charged are state owned. Again, a parallel problem exists with respect to state and local systems of emission charges, where courts may question the power of one unit of state government to tax another unit.

Finally, if emission charges are construed as taxes, the statutory authorization must originate in the popular chambers of federal and state legislatures, which, on the federal level, is the House of Representatives. This point could pose a problem if Congress were to pass a Senate-originated bill involving emission charges that is later interpreted as a taxation measure by the courts.

The foregoing discussion does not argue that emission charges will be treated as taxes, but only that charges might be so treated and outlines the uncertain consequences. It is mainly because both emission charges and taxes raise revenue that a court-drawn analogy between the two is foreseeable. However, there are also reasons for not treating emission charges as taxes.

Emission Charges Distinguished from Taxes

First, emission charges can be distinguished from most, if not all, taxes. The primary purpose of emission charges is not raising revenue, which is usually seen as the primary purpose of a tax, but rather to encourage the proper level of emission reduction at a minimal administrative cost. Second, there is no need to place extra constraints on the government's authority to impose emission charges by calling them taxes. As discussed above, it appears that there may be stricter restraints on the government's authority to tax than on the government's authority to regulate. To the extent that this is so, it can probably be ascribed to the view that the authority to tax is stronger than the authority to regulate. At least so far as emission charges are concerned, we think this is an inaccurate perception.

Emission charges involve no greater interference with noise emitters than would direct controls, either in the form of emission limitations or of equipment specifications. In fact, one of the justifications for emission charges is that they involve less interference with the emitter. Each emitter is free to decide what degree of noise abatement to achieve and how to achieve it, subject only to the constraint of paying the cost of the unabated noise through the emission charge. Since emission charges thus interfere with emitters even less than do more traditional types of regulations, the legal safeguards applied to limit governmental power in the case of regulations should be sufficient; such additional safeguards as may apply to the taxing power are unnecessary.

Fines

A fine is a charge levied on a party as a penalty for violating a legal standard. There are two types of fines: criminal and civil. The distinction between the two is sometimes unclear, but can be important; more procedural protections must be given to noise emitters if the charges are treated as criminal fines than if they are treated as civil fines.

However emission charges are characterized, courts are likely to find that each emitter must have the opportunity for some sort of hearing before being required to pay the charges. The alleged emitter must have the opportunity to challenge both the validity of the charge scheme and the accuracy of the specific charge assessed against it. However, the procedural protections that must be afforded to a source at the hearing may vary greatly depending on how the charge is characterized.

If emission charges are treated as criminal fines, the law would afford many procedural safeguards to the emitter at a hearing. For example, individual court trials with a judge presiding would be required before a charge could be enforced against a noise emitter, the emitter would have a right to a jury trial, and emission levels would have to be proved beyond a reasonable doubt instead of only by a preponderance of the evidence. It is also likely, but not certain, that each emitter could challenge the validity of the charge scheme and the charge schedule at the time of the enforcement action. These requirements would substantially increase the cost of administering a system of emission charges. They would also hamper its operation by decreasing the likelihood that an emitter would have to pay a charge. This, in turn, would probably decrease voluntary compliance because an emitter would be encouraged not to pay a charge if it found that sanctions for not paying were unlikely.

It is not clear what procedural requirements would apply to emission charges if they are treated as civil fines. Most likely, each emitter would still have a right to an individual hearing on the level of its emissions. These hearings could probably be held before an agency rather than a court, with some formalities eliminated. For example, there may be no jury trial or formal rules of evidence, but an emitter would probably retain the right to be represented by counsel and to have all evidence that is to be used against it presented at the hearing. Courts would most likely review the agency proceedings but not rehear the evidence. Also, it is more likely, but still not certain, that challenges to the charge schedule could be limited to the time the schedule is promulgated and not permitted at the time of enforcement. These procedures reduce the cost and uncertainty associated with enforcing fines.

Another legal impediment to civil fines that might be applied to emission charges could arise at the state and local level. State courts may view imposition of civil fines as a judicial function and prohibit charge assessments by a state administrative agency as an improper usurpation of judicial power. While there is no similar usurpation problem at the federal level, state courts are free to assert their own views on the powers of the various branches of state government when state assessments are involved. Some state courts have allowed administrative agencies to impose civil fines, but other states may not do so.

Having examined the consequences of treating emission charges as fines, we turn to the question of whether they should be so treated. There are a number of significant distinctions between emission charges and criminal fines that have led writers on the subject to argue that the two should not be treated alike. Assessment of emission charges do not involve a collective judgment on the character of the emitter or on the social desirability of its conduct, while criminal fines indicate collective condemnation of the criminal's character and conduct. Emission charges are not designed to force adherence to some fixed standard, as are criminal fines. In addition, it is appropriate to deny the procedural protections associated with criminal penalties to noise emitters. In the case of criminal fines, it is so important to protect a person from wrongful condemnation or incarceration that it is worthwhile to require protective procedures involving high costs and a significant chance of erroneous acquittal of the accused. Where neither the element of collective condemnation nor potential incarceration exists, the high cost and inefficiency of the criminal justice system is not justified.

The argument for distinguishing emission charges from civil fines is not as clear, partly because the characteristics of civil fines are not well defined. Some distinctions can be drawn. Civil fines are sanctions for violation of some norm, but there are no norms involved in a system of emission charges intended to force a noise emitter to bear the full costs of its emissions. On the other hand, when the charges are designed specifically to encourage noise reduction to some predetermined target level, noise emission charges look more like civil fines.

There is another distinction from civil fines. In the case of a fine, a party who violates a standard and pays the fine is thought to have committed a "wrong" in having exceeded or violated the standard and is not privileged to continue the violation. In the case of an emission charge, no concept of "wrong" applies, and an emitter who regularly pays the charge is privileged to exceed any target level.

Regulations

Not all the potential legal constraints on emission charges result from the chance that they will be treated by analogy to other charge devices. Even if a court recognizes emission charges as a unique regulatory device, it must decide whether the agency that tries to regulate noise through emission charges, rather than through some type of direct controls, has the statutory authority to do so. May emission charges be imposed under a statute that only provides authority to "regulate" noise, or is specific statutory authority for the charges required?

It would be safest to set emission charges under a statute specifically authorizing them. Without such specific authorization, there is precedent indicating that a federal agency could impose emission charges for noise under a statute authorizing regulation only if the legislative history (i.e., committee reports and Congressional floor debates) indicated that Congress had intended that emission charges be among the regulatory techniques that might be used.

There remains the question of whether an agency could use emission charges as a regulatory technique when such charges are not specifically authorized by either the statutory language or its legislative history. There is no precedent holding that such charges would not be permissible. Whether such charges would be allowed is probably tied in part to the question of how a court would characterize the charges. Charges that are characterized as taxes are most likely to be held beyond an agency's authority; charges treated as a unique regulatory device, least likely. Moreover, the more closely emission charges are shown to be reasonably related to a statutory goal, the more likely they are to be held valid without specific statutory authorization. Thus, if the statutory goal, as stated by the legislature, is reduction of noise emissions, an agency promulgating emission charges may be called on to show that the charges are calculated to reduce noise levels. (It would no doubt be helpful if the agency were to explain why emission charges were preferred over other control devices.) On the other hand, if the statutory goal is attainment of "the optimal level" of noise emissions, the agency would not necessarily have to show that emission charges are calculated to reduce noise, but only that the charges are calculated to optimize levels of noise emission.

In summary, there is some risk that agency action imposing emission charges that are not specifically authorized by statute or legislative history would be found invalid. This risk can probably be diminished by careful agency explanation of the rationale behind the charges as a form of regulation. When legislation is being drafted, it would be wise to include explicit authorization for emission charges.

LEGAL CONSTRAINTS ON GOVERNMENTAL REGULATION OF AESTHETIC HARM

To a significant extent, the harm done by noise appears to be aesthetic. Aesthetic harm, as the term is used here, is not limited to infringement on one's preferences, but encompasses all harms not correlated with demonstrable physical or psychological harm. This corresponds in part to what is also called annoyance (see Chapter 6). In addition, however, it may well encompass harmful physical or psychological effects that cannot be immediately demonstrated, for the effects of noise exposure are seldom sudden or immediate. While we can rarely prove that noise causes specific physical or psychological harm, we know that many people object to noise. Because controls on noise, perhaps more than controls on other types of environmental pollutants, rely on aesthetic grounds for their justification, we must consider the legal position of measures designed to abate aesthetic damage.

Any scheme of governmental control involves the imposition of costs on at least some of the parties subject to such control. Simple fairness as well as legal notions of due process generally require that two factors be present before control costs may be imposed on a private party by the government. First, there must be a legally cognizable harm. Second, there must be a determination that the party who is charged with the cost is the one who caused the harm. The first of these factors presents more of a problem when dealing with noise emissions than when dealing with many other pollutants. The problem is whether the harm caused by noise is legally cognizable. What constraints are there on legal cognizance of aesthetic harm?

One of the two sources of law on this issue is law on court-imposed sanctions on actions by private individuals for aesthetic interference. The second source results from some governmental regulatory schemes designed to alleviate aesthetic harm or to enhance aesthetic values.

The main source of private law is the law of private nuisance, which provides a remedy to one person against a neighbor who causes an unreasonable interference with the use and enjoyment of the person's land. We may look at how courts have reacted to claims that noise is an unreasonable interference to determine whether noise is regarded as a legally cognizable harm. In general, we find that it is so regarded if the noise is substantial. On the other hand, courts are reluctant to recognize some aesthetic interferences, particularly when the degree of interference is difficult to measure. This measurement issue arises with regard to noise but is less problematic than for some other aesthetic values, such as visual ugliness. There are reasonably good techniques for measuring the amount of noise, if not the discomfort it causes.

There is also widespread acceptance of aesthetic interference as a legally cognizable harm that may be subjected to governmental regulation. Even if courts are themselves hesitant to measure aesthetic qualities or to balance them against other values, they will usually defer to attempts by legislatures or administrative agencies to do so. Legislatures earn this deference by right of their political mandate; agencies earn it by their expertise. Thus, local zoning regulations based on aesthetic values alone, that is, schemes designed to protect natural beauty, have been upheld. On the federal level, there are numerous regulatory statutes designed to protect the public health and welfare, and public welfare almost certainly includes aesthetic values. While we have found no federal laws that provide for regulation of private activity on aesthetic grounds alone, we find no reason why statutes or regulations of this sort would not be valid. The power of Congress to decide what societal values should be protected is broad. Moreover, even where the harm appears to be mainly aesthetic, the chance that there may also be physical harm may be used as the basis for regulation. Congress may, and indeed has, found that the potential health hazard from noise is reason for regulating noise emissions.

Other subtle stumbling blocks may exist in the area of regulations based on aesthetics. A statute or regulation that is qualitative, rather than quantitative, may be found invalid as impermissibly vague. More importantly, qualitative ordinances create enforcement problems, particularly in proving the existence of noise exceeding the stated standard. But these are potential pitfalls for the drafter of the regulatory provision and do not detract from the general proposition that regulation for aesthetic purposes is acceptable.

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II

TRANSPORTATION NOISE: ITS MEASUREMENT, SOURCES, AND PROSPECTS

3 Noise Indices

INTRODUCTION

This chapter describes the different measures used to assess human exposure to sound and to show their interrelations. Because of the multivariate character of sound, a number of different elements usually enter into the calculation of a measure. Such a combined measure is called an index.

Since no single number can accurately reflect the behavior of a multiplicity of variables, there can be no "ideal" noise index. Any index is a combination of the variables representing the relevant attributes of the sound, such as intensity, frequency spectrum, duration, and intermittency. Moreover, the combination most appropriate for one purpose will give more weight to certain attributes than will the combination for some other purpose. Thus it is quite natural that a number of different noise indices are currently in use, and it is futile to search for any single index capable of serving all the different purposes for which indices are used.

It is not our aim here to provide details sufficient to permit the reader to calculate a given index from the material provided, but, rather, to describe enough about the different indices to indicate the nature of their construction and to offer a comparison of their objectives. Besides describing the indices that are used most widely, this chapter indicates the costs of obtaining the required data and calculating a given index so that the total cost of a monitoring program can be assessed.

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NOISE

Noise is often defined as unwanted sound. Such a definition makes it clear that the designation of a given sound as noise is a matter of human evaluation. Obviously, people will differ in their evaluations and even the same person may change an evaluation from one time or circumstance to another. Some sounds also have special meanings, such as a baby's cry to its mother. No index attempts to measure such individual differences in the evaluation of sound. Rather, measures of noisiness are intended to reflect the fact that at an intensity sufficiently high most people will display an antipathy to sound. It is this common judgment that has served as the basis for the design of noise indices.

DECIBELS

All of the basic noise measures use decibels as a unit. The decibel (dB) is simply a logarithmic transformation of the basic measure of sound intensity (energy). Such a logarithmic transformation is convenient because it makes it easier to deal with the enormous range of intensities that people can hear. Its main characteristic is that a given increase in the logarithm corresponds to a given ratio in the basic number rather than a given absolute change. In a fairly quiet location, a given rise in decibel level will mean a fairly small rise in absolute noise level, say measured in watts/cm^2, because a given ratio of a small number is still a small number, while under noisy conditions an equal rise in decibel level can indicate a relatively large increase in absolute noise.

Zero decibels on a scale of sound pressure level is nearly the threshold of sound at 3000 cycles per second—that is, it is the softest sound that can just be heard when the frequency is near the highest note of a piano. Sixty decibels is moderate speech heard at 1 meter, and 90 dB is the sound one hears on a subway platform when the train arrives. At 110 and 120 dB the sound is so intense that most people start to complain about pain or tickle in their ears.

Doubling the intensity of sound pressure is equivalent to an increase of 3 dB. However, if one asks people to double the loudness of a given sound, there will be a range of judgments, from about 5 dB to 15 dB, but the mean setting will probably be about 10 dB. Thus, changing a sound from 40 dB to 80 dB does not double the loudness, it doubles it 4 times—a 16-fold increase in loudness. Incidentally, 40 dB and 80 dB correspond, respectively, roughly to a whisper and a shout, heard at about 1 meter.

NOISE EXPOSURE INDICES

A striking feature of the study of noise control is the variety of different indices and units of measurement that are used. Loudness level (LL), perceived noise level (PNL), and speech interference level (SIL), are some of the quantities proposed to measure the magnitude of noise. In addition, the noise number index (NNI), noise pollution level (NPL), noise exposure forecast (NEF), and many other indices demonstrate the different procedures used to assess noise exposure in different situations. It is natural to ask why specialists have not settled on a single method for the assessment of noise magnitude or exposure. There is no simple answer to that question, other than the obvious one that different measures were suggested by different groups to satisfy different requirements.

Differences in the treatment of the sheer energy content of a sound are relatively slight and do not change much from one source to another. Significant variations in the indices result from differences in the uses for which they are intended. For example, a noise index appropriate for a turbine generator probably does not need to assign an important role to a measure of intermittency. After all, the turbine should, under normal circumstances, run continuously. However, intermittency is a primary characteristic of other types of industrial and construction noise: the sound of a pile driver, for example, is seldom steady and the components of an index used to evaluate it should include the duration of the exposure and the number of noise events. Aircraft flyovers also fall into this class and, over the years, a number of special components have been added to the basic measure of intensity in order to provide a better assessment of exposure to noise from these sources.

In our judgment, the major differences among indices result from differences among the elements or components used in making up the composite index. These components are often evaluated differently in different indices. The inclusion or exclusion of different elements in a particular noise index is probably the natural result of the specific application for which the measure was devised.

There are many reasons for desiring a single noise index: regulation would be facilitated because standards could be based on a single, comparable, scale; instrumentation could be standardized and the cost of monitoring would be reduced; and informing the public about noise would be easier. But effective noise abatement need not await the adoption of a single noise index because the differences among the measures and indices are relatively small compared with other uncertainties. Often the differences among different measures is only 1 or 2 dB. This is much less than the variability one would encounter if one asked a group of subjects to adjust two sounds to be equally "noisy." Such variability can be at least five times greater. But while such differences in the indices are relatively small compared to the variations in subjective responses, this does not prevent heated controversy. Differences of 1 or 2 dB become important when limits or noise ceilings are proposed and the economic implications of these small differences are not trivial.

This discussion is intended to identify and compare the elements of the different noise indices and to provide approximations that are useful in comparing one noise index with another.

NOISE MAGNITUDE

Central to any noise index is an assessment of the magnitude of the sound. Sound affects people by its threat of hearing damage, through its capacity to annoy, or through other effects on behavior. But any of these effects can be produced only by the physical process that generates the sound.

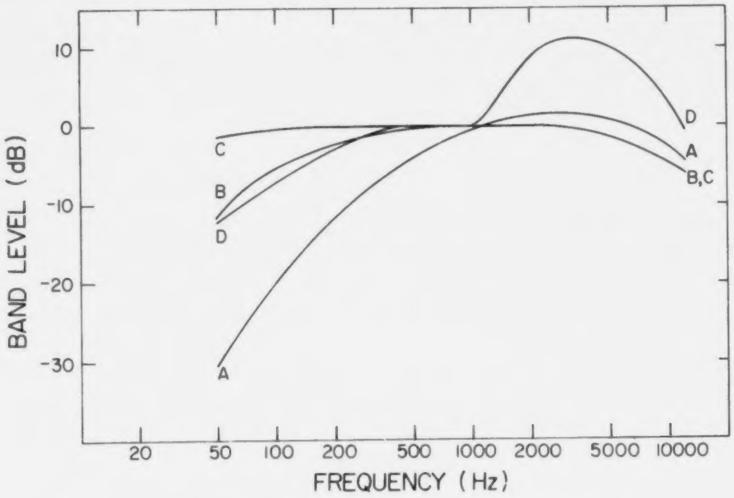
Physically, sound can be defined as a mechanical disturbance propagated in an elastic medium. The elastic medium is the air or atmosphere and the mechanical disturbance can be thought of as a variation in pressure. At any point in space there is an average level of pressure, the atmospheric pressure, and sound is a relatively rapid fluctuation in this average pressure. This fluctuation travels through space as a wave.

For most purposes, an adequate physical description of sound is provided by the variation in pressure measured by a microphone placed near a subject's ear. Initially we will deal with this aspect of sound, ignoring other variables such as duration, repetition rate, etc. There are two general classes of measures of the magnitude of a sound: direct measures and derived measures.

Direct Measures

Because of the physical structure of our ears, some sounds are easier to hear than others even when they are equal in energy. We can most easily hear energy in the frequency region near 3000 cycles per second. The unit of frequency, cycles per second, is designated as Hertz (Hz), after the physicist. Sound whose predominant energy lies at frequencies below 100 Hz or above 10,000 Hz may require a million times more energy to sound as loud as a 3000-Hz component.

Various functions have been proposed to provide weights for each frequency in the spectrum in order to reflect the ear's differential



SOURCE: Pearsons (1973).

FIGURE 3.1 Four common frequency weightings used in direct measurement of sound.

sensitivity to frequency. These direct measures apply a weighting to the overall spectrum of the sound; that is, they selectively weight pressure variations at different frequencies. The weighted pressures are then squared and combined to obtain a single number. The logarithm of this quantity is proportional to its decibel value and is called a sound level. The weighting network is usually specified by an adjective preceding sound level, for example, the A-weighted sound level or simply sound level A.

Figure 3.1 shows four common weights used in direct measurement of sound. The weights are somewhat different and thus a given sound's A-weighted level will be different from its C-weighted level, but both will be expressed in decibel units. These different weighting structures have been constructed because each serves some purposes better than the others. Often these units are labeled as dB(A), dB(C), etc. This is technically incorrect because it is not the decibel, but the sound level that is A, B, or C weighted, but the practice occurs and it need not lead to confusion if its meaning is understood.

(Sound level, using A, B, or C weights, is usually measured by a meter satisfying requirements of American National Standard Specification for

Sound Level Meters S1.4-1971. The meter has two dynamic characteristics. One, called the fast setting, integrates sound over an interval of about 250 milliseconds. The second, called slow, integrates over a longer period of time, about 2000 milliseconds.)

Derived Measures

Derived measures were first proposed because in some circumstances it was felt that a better correlation with people's assessment of the magnitude of a sound can be obtained by using a somewhat more complicated combination rule to aggregate the sound pressure levels at the different frequencies.

Derived measures of sound are obtained from physical measurement of the sound pressure level in successive frequency bands over the entire spectrum, for example, in an octave or a third-octave band. From these various sound pressure levels, some combination rule is used to derive an overall estimate of a level. Two common methods are used to estimate loudness levels: one is Stevens' Mark VI loudness level (SLL), the other is Zwicker's loudness level (ZLL).

Stevens' method converts the sound pressure level in each band to an equivalent loudness. The various loudnesses are combined via a nonlinear combination rule that gives maximum weight to the loudest band. Zwicker's method is essentially geometric and attempts to calculate the total loudness of the sound by integrating the loudnesses over all frequencies. It is a nonlinear combination, however, since effects of masking (the fact that one sound can render another inaudible) are explicitly considered in combining adjacent bands. Both have been used in international standards for noise, International Standardization Organization (ISO) R592.

Another measure of noise magnitude is perceived noise level (PNL), a method devised by Kryter and similar in form to Stevens' loudness level. It is also employed in an international standard, for aircraft noise, ISO R507. The vast majority of noise indices employ one of the preceding as the basic measure of noise magnitude. Because sound is often annoying simply because it interferes with speech, another derived measure, called speech interference level (SIL), has also been used on some occasions. It is an arithmetic average of sound pressure levels calculated in four octave bands with center frequencies of 500, 1000, 2000, and 4000 Hz.

Finally, Stevens (1972) has designed a revised version of his loudness level calculation called perceived level of noise (Mark VII), which makes use of revised equal loudness scales. It has been little used as yet.

SOUNDS THAT VARY

While magnitude is an important characteristic of steady sounds, many sounds are not steady. The airplane flyover is a prime example. A passing car, lawn-mower noise, and many sounds created by machinery are intermittent or vary in intensity as time passes. There are three measures of noise magnitude that assess the level of a sound whose magnitude is not constant:

1. Maximum sound level (SLAM)—the greatest sound level during a designated time interval or event. We use the term to mean the greatest A-weighted sound level of an event recorded on the fast setting of a sound level meter. The measured quantity in decibels is denoted L_{max}.
2. Average or Equivalent Sound Level (SLAQ)—a sound level typical of the sound levels at a certain place in a stated time period. Technically, average sound level in decibels is a mean-square, A-weighted sound pressure level over the stated time period, unless some other frequency weighting is specified. Average sound level differs from sound level in that average sound level gives equal emphasis to all sounds within the stated averaging period. The measured quantity in decibels is denoted L_{eq}.
3. Sound Exposure Level (SEL)—the level of sound accumulated during a given time period or event. The SEL is particularly appropriate for a discrete event such as the passage of an airplane, a railroad train, or a truck. It is not an average, but a kind of sum. In contrast with average sound level, which may tend to stay relatively constant even though the sound fluctuates, sound exposure level increases continuously with the passing of time. Technically, sound exposure level, in decibels, is the level of the time integral of the square of the A-weighted sound pressure. The measured quantity in decibels is denoted L_{AE}. For a very steady sound, the maximum and average sound level (averaged over the time the sound is steady) will be nearly the same. For the same sound, the total energy will double for each doubling of duration and, hence, if the sound is a discrete event, the sound exposure level will increase 3 dB (3 dB per each doubling of duration).

Many discrete sounds are so much larger than the background level that the equivalent or total exposure level can be calculated on the basis of the discrete events. For example, if the N discrete events are nearly equal in level and last for T seconds at this constant level, then the sound exposure for each discrete event is simply:

$$L_{AE} = L_{max} + 10 \log T.$$

If one wished to compute the equivalent sound level for N equal sounds in a 24-hour period, then, since 10 log 86,400 = 49.6 dB (86,400 sec in a 24-hour period):

$$L^{24}{}_{h} = \mathrm{SEL} + 10 \log N - 49.6 \text{ dB}.$$

Interestingly, this approximation can be used for airports with moderate traffic loads because the noise produced by each landing and takeoff is so much larger than the background level that the L_{eq} is dominated by these discrete events even if the averaging period is as long as 24 hours.

CORRECTION FACTORS

Besides the average or integrated magnitude of a sound, the disturbance created by some sound is affected by a number of other variables such as the time of day or the presence of audible tones. These variables, referred to as correction factors and indicated by the letter F and a number, are used to amend the noise magnitude to arrive at an index that more nearly reflects the objectionable quality of a particular sound exposure. (These corrections are made by adding or subtracting decibels from the original assessment of magnitude. Thus the correction terms are additive, but because of the logarithmic character of the decibel measure, they correspond to multiplication of the base quantities.) This section first lists the various correction factors, then presents a table indicating which indices take account of which factors.

There are nine commonly used correction factors:

F1. Duration of the Sound—the length of time during which the sound is emitted.

F2. Frequency of Occurrence of Noise—a correction that indicates the number of noise events that occur in a specified length of time, such as the number of aircraft flyovers during a 24-hour period. This sometimes is evaluated in terms of percentage of time that a source operates in a given period.

F3. Discrete Frequency Components in Noise—a correction for the presence of audible pure-tone components in noise: i.e., distinctive pitches that are apparent in the source.

F4. Impulsive Nature of Noise—a correction for noise that is composed of discrete impulses, such as the noise produced by an air hammer.

F5. Background Noise—the average noise level when the source is not operating. Some measures of noise magnitude, such as L_{eq} or SEL, automatically reflect the background sound level. Some indices require one to calculate explicitly the background level, with the source removed, and then to add a correction based on the increment caused by reintroduction of the source in question.

F6. Variability of Noise—a measure of how much the noise fluctuates over a given time period.

F7. Time of Day—a correction for the time of day in which noise occurs. Typically, indices impose a penalty for night-time as opposed to day-time occurrences.

F8. Time of Year—a correction for the season in which the noise occurs. An index may impose a penalty for a summer exposure as opposed to a winter exposure because building windows are left open in the summer.

F9. Previous Exposure of the Community to Noise—a correction that assumes that communities with previous exposure to noise levels that approximate the new noise level will be less likely to protest the added noise, provided that the total noise level is below some maximum value.

Table 3.1 lists these correction factors and indicates which indices take which factors into account. The first column in Table 3.1 lists the index, the second column gives the common abbreviation for that index, and the third column gives the symbol used to denote the quantity. The division of the table into two parts notes that either A-weighted sound level or PNL is used as the means of assessing noise magnitude.

RELATIONS AMONG INDICES AND MEASURES OF NOISE MAGNITUDE

Given the dozen or more available noise indices, it is essential to understand how any one of these indices is related to any other one. Since the indices are different, the measures they yield for a given source will be different. The correlation among the different measures is surprisingly strong (about 0.95 [Young 1964]), and one can often approximate the relation among the indices by a simple additive constant. Thus, for a variety of noise sources, sound level A plus 13 dB is approximately equal to PNL. In fact, the relation depends on the distribution of energy over frequency for each source. In most cases, the source is an airplane, since this has been the most frequent noise source measured.

Rather than attempt to relate every index to every other, we will use A-weighted sound level (L_A) or the average sound level (L_{eq}) as our common basis for comparison. Table 3.2 shows the approximation between the various measures of noise magnitude and the corresponding A-weighted level.

TABLE 3.1 Correction Factors Used by Various Noise Indices

Noise Index	Abbreviation	Symbol	Duration F1.	Frequency of Occurrence F2.	Pure Tone F3.	Impulse F4.	Background F5.	Variability F6.	Day–Night F7.	Seasonal F8.	Previous Experience F9.
Based on A Level											
Single Event											
Sound exposure level	SEL	L_{AE}	x								
Multiple Events											
Community noise equivalent level[1]	CNEL	–	x or	x					x		
Day-night average sound level[1]	DNL	L_{dn}	x						x		
Equivalent sound level[1]	EQL	L_{eq}	x								

Mean annoyance level[1]	Q	–	x	x							
Noise pollution level[2]	NPL	–	x					x			
Noisiness index[1]	NI	–	x		x				x	x	
Total noise load[1]	B	–	x or	x					x		
Traffic noise index[2]	TNI	–					x	x			
Based on Perceived Noise Level											
Single Event											
Effective perceived noise level[1]	EPNL	–	x		x						
Tone corrected perceived noise level[1]	PNLT	–			x						
Multiple Events											
Composite noise rating[2] (Airport–FAA-DOD)	CNR	–		x					x	x	
Composite noise rating (community)[2]	CNR	–		x	x	x	x		x	x	x
Isopsophic index[2]	N	–	x								
Noise and number index[2]	NNI	–		x							
Noise exposure forecast[2]	NEF	–	x	x	x				x		

[1] Data from Pearsons and Bennett (1974).

[2] Data from Pearsons and Bennett (1974) and Shultz (1972).

TABLE 3.2 Approximate Relations Among Measures of Noise Magnitude

Source	Measure
Aircraft	$L_B = L_A + 3^a$
	$L_C = L_A + 3^a$
	$L_D = L_A + 6^a$
	$SLL = L_A + 9^b$
	$ZLL = L_A + 14^c$
	$PNL = L_A + 13^d$
Mixture (Manufacturing, Neighborhood, Vehicle and Aircraft)	$SLL = L_A + 10^e$
	$ZLL = L_A + 15^f$ 20^g
	$PNL = L_A + 13^e$
Broadband Flat Noise	$L_B = L_A - 1^a$
	$L_C = L_A - 1^a$
	$L_D = L_A + 8^h$

[a] From U.S. EPA (1974).
[b] From Young and Peterson (1969).
[c] Indirect via SLL + 5 dB = ZLL (see Schultz 1972).
[d] From Peterson and Gross (1972) and Schultz (1972).
[e] From Botsford (1969) and Parkin (1964).
[f] From Botsford (1969).
[g] From Parkin (1964).
[h] Computed from the area under the weighting curve (see Figure 3.1).

One other set of approximations is extremely useful:

$$L_{dn} \sim CNEL \sim NEF + 35\ \text{dB} \approx CNR - 35\ \text{dB}$$

The last relation is less precise and this is indicated by the double approximation sign.

EVALUATING A SINGLE NOISE SOURCE

Practically the entire discussion has been devoted to measurement at a given place—the noise near an airport, urban streets, or a given neighborhood. Attempts to regulate will undoubtedly continue to impose limits on the noise exposure as monitored in these places. But one can also measure single sources and attempt to control the total sound in a given place by monitoring each of the contributing sources.

In some cases this can be reasonably successful and one can actually predict the noise level at a given place from the individual sources. The noise near airports is a prime example. If one knows what planes are using the airport and how often each type is landing and taking off, one can calculate the contribution of each type of plane to the total noise exposure with a fair degree of accuracy.

One cannot do as well on a given street corner because all cars are not alike, and even the same model of automobile may have a quiet or noisy muffler. In addition, buildings reflect sound and cause reverberation and may make a car in one lane more noisy than the same car in a different lane. The testing of vehicle noise is therefore usually carried out in an open environment, with no structures or buildings nearby.

Trucks are a source of vehicular noise that present special measurement problems. Two trucks of a manufacturer may differ widely in the noise they generate because of differences in tires, mufflers, cooling fans, and transmissions. One can, however, predict with reasonable accuracy the noise a truck will generate—in a given circumstance—if one knows the various components that the truck uses. Work has begun on a volume that is tantamount to a noise catalogue that permits one to evaluate the various options that the truck may select and combine these into a reasonably accurate prediction of the total noise it will generate per mile of operation under "typical" driving conditions.

COST ESTIMATES FOR MONITORING

A noise abatement plan necessarily requires a continuing program of monitoring either of the sound levels at some place or of the sound levels of some sources to assure compliance. The cost of such monitoring programs will vary depending on which index is employed.

Table 3.3 lists some of the indices and indicates the equipment one could use in calculating the particular index. The minimum and maximum cost for such equipment is also listed. The total cost is difficult to estimate with any precision because it depends on many circumstances. For example, whether the index is calculated once or will be calculated periodically over some longer period, such as a month or a year, will influence the level of investment in automatic equipment. Large investments in automatic equipment along with more frequent use will, of course, yield lower costs per calculation. We have somewhat arbitrarily designated the total costs as "high," "moderate," and "low." These correspond to the indicated ranges of dollar cost when we estimate the cost for a single non-recurrent measurement. (The labor costs are not more than a few person-hours for any index.) Other estimates for the

TABLE 3.3 Instruments Required and Cost Estimates for Various Indices

Measure or Index	Sound Level Meter	Spectrum Analyzer (1/3 Octave)	Tape Recorder	Graphic Level Recorder	Sound Level Equivalent Meter	Statistical Distribution of Sound Levels	Digital Computer with Interface	Total Cost for Equipment Needed to Calculate Index
PNLT	x	x	x				x	High
EPNL	x	x	x	x			x	High
SEL			x		x		x	Med
CNR	x	x	x				x	High
NEF	x	x	x	x			x	High
CNEL	x		x		x		x	High
L_{eq}	0		0		x		0	Low-Med
L_{dn}	0		0		x		0	Low-Med
N	x	x	x	x			x	High
Q	x		x	x			x	High
NNI	x	x	x				x	High
NI	x	x	x	x			x	High
B	x		x				x	Med
TNI	x		x			x	0	Low-Med
NPL	x				x	x	x	High
Minimum Cost ($)	300	5,000	500	3,300	3,100		8,000	
Maximum Cost ($)	1,600	30,000	3,000	4,000	3,400		20,000	

x = required
0 = optional
High > $10,000/single nonrecurrent measurement
10,000 > Med > 5,000
Low < 5,000

costs of noise monitoring can be found in a report by Wyle Laboratories (1976).

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4 Noise from Transportation Sources

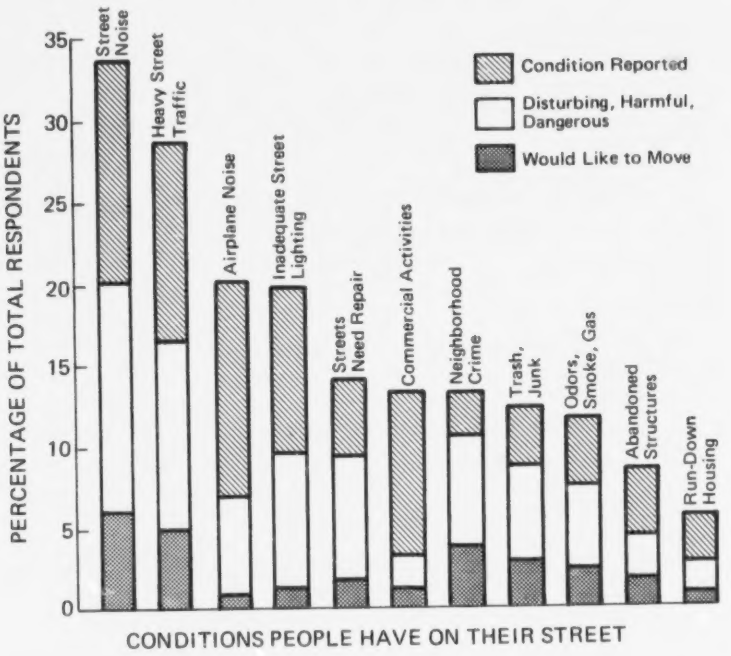
NATURE AND EXTENT OF THE IMPACT OF NOISE

The noise from transportation and other sources has significant effects upon a large segment of the U.S. population. These effects are of two basic types (U.S. EPA 1974):

- hazardous exposures potentially leading to permanent hearing loss, and
- interference with human activity such as speech communication and sleep and various forms of annoyance.

It is estimated (U.S. EPA 1972; Bolt Beranek and Newman, Inc. 1976; Galloway et al. 1974) that as many as 20 million people are exposed to noises of duration and intensity sufficient to cause a permanent reduction in their ability to hear. Of these, approximately 9 million are production workers in industry, 1 million are operators of transportation equipment, 2 million are passengers, and 8 million are operators or passengers of recreational equipment and other equipment for personal use.

Noise is the most frequently cited cause of annoyance in neighborhoods. In a 1973 national survey (U.S. Bureau of the Census 1975) of housing conditions, street noise was cited by 34 percent of the 60,000 respondents as a "condition existing in this neighborhood"; 60 percent of those reporting its presence felt that the street noise was "disturbing, harmful, or dangerous"; and 18 percent of those reporting the condition



SOURCE: U.S. Bureau of the Census (1975)

FIGURE 4.1 Results of 1973 survey on neighborhood conditions.

felt that "it is so objectionable" that they would "like to move." In addition, 20 percent of the respondents listed airplane noise among the conditions characterizing their neighborhood, of whom 34 percent were disturbed by it and 6 percent wished to move because of it. Figure 4.1 shows the data from this survey.

When the respondents in the survey were asked which attributes they considered "disturbing, harmful, or dangerous," street noise was the one most often cited; heavy street traffic was second. (This is indicated by the heavily cross-hatched middle section of the bars in Figure 4.1.) These noises were considered more bothersome than the other attributes reported. Airplane noise, though cited third most often as an attribute of the neighborhood, was cited as less "disturbing, harmful, or dangerous" than crime, street lighting, street repair, trash and junk, and odors, but more so than abandoned structures, rundown housing, and commercial activity.

Extrapolating from these data, it has been estimated that more than 41 million Americans find street noise disturbing and more than 12 million people would like to move because of it. Further, more than 14 million Americans find aircraft noise disturbing, and 2.6 million would like to move away from it.

A 1970 survey (Bolt Beranek and Newman, Inc. 1971b) conducted for the Automobile Manufacturers Association found motor vehicles to be the most frequently cited source of annoying noise: 72 percent of the 1200 respondents in this survey classified their neighborhoods as noisy, and 55 percent of them cited motor vehicles as the primary cause. Thus, in this survey, which was conducted in urban areas remote from airports, approximately 40 percent of those surveyed were annoyed primarily by the noise of motor vehicles. This result agrees substantially with the 1975 housing survey cited above (allowing for the fact that the housing survey used a sample of all neighborhoods, urban and rural, near to and far from airports), in which 34 percent of those questioned cited street noise as a "condition" in their neighborhood. Other results of this 1970 survey are reported in Table 4.1.

In 1974, a survey was conducted of 2000 individuals living in 24 urban

TABLE 4.1 Percent Contribution of Each Source Indicated by Respondents Classifying Their Neighborhood as Noisy (72% of 1200 Respondents)

Source	Percentage
Motor vehicles	55
Aircraft	15
Voices	12
Radio and TV sets	2
Home maintenance equipment	2
Construction	1
Industrial	1
Other noises	6
Not ascertained	8

SOURCE: U.S. EPA (1973a).

TABLE 4.2 24 Site Survey Noise Sources Ranked by Percent of Urban Population Highly Annoyed at Sites Remote from Freeways and Airports

Rank	Source	% H.A.
1	Motorcycles	11.7
2	Large trucks	6.9
3	Autos	6.5
4	Construction	5.8
5	Sport cars	5.4
6	Helicopters	4.0
7	Constant traffic	3.9
8	Airplanes	3.4
9	Small trucks	3.1
10	Buses	2.8
11	Power garden equipment	1.9

SOURCE: Fidell, S. (1977) Analysis of the National Urban Noise Survey. Bolt Beranek and Newman Report 341 2. Draft submitted to U.S. EPA.

neighborhoods.[1] The neighborhoods were selected to be representative of the distribution of the total urban population and its census tract density, but the areas surveyed were deliberately chosen to be relatively remote from both airports and freeways. This survey offers additional evidence about the types of noise sources found annoying.

Each respondent was asked, "Over the past year, have you heard . . . [source] in your neighborhood?" The sources listed included three types of human and animal sounds and 11 categories of sounds of mechanical origin, and the questionnaire allowed the respondent to add to the list. Again, the noise of motor vehicles was at the top of the list, with 12.6 percent of the respondents reporting that it was "highly annoying." When motor vehicles were subdivided into different categories, motorcycles ranked first in annoyance, followed by large trucks, autos, sports cars, constant traffic, and buses. Table 4.2 summarizes the rank order in terms of annoyance for noise sources in urban areas remote from freeways and airports. Table 4.3 indicates the other noise sources specified by respondents. It should be noted that many of these sources are characterized as intrusive, although they do not occur with sufficient frequency to affect cumulative noise levels.

[1] Fidell, S. (1977) Analysis of the National Urban Noise Survey. Bolt Beranek and Newman Report 3412. Draft submitted to U.S. EPA.

The results of the three questions on people and animal sounds showed that: 4.9 percent are highly annoyed by "other people's radio or TV"; 12.1 percent are highly annoyed by noise from "pet animals"; and 6.8 percent are highly annoyed by "people's voices."

The percentage of people annoyed by radio or TV and by pet animals showed little variation with population density, but the annoyance with other people's voices was directly related to population density. Very little annoyance was indicated at low population densities, but a considerable amount of annoyance was reported in densely populated urban areas. These survey results do not differentiate between voices of people outdoors and voices of people in adjoining apartments, heard through common walls. They suggest that if the level of traffic noise in urban areas were reduced by a large amount, it might be replaced as a source of annoyance by people's voices intruding from outside the dwelling.

In summary, the public's perception of environmental noise in residential areas in terms of annoyance is rather well documented. Motor vehicles are the source of noise most often cited, with aircraft noise ranking second in the surveys that sample the entire population. Noise produced by other individuals and animals is third, followed by noise

TABLE 4.3 24-Site Survey Other Sources Rated Highly Annoying

Rank	Source	No. of Sites	Total Mentions
1	Sirens	8	14
2	Fire trucks	7	12
3	Ice cream trucks	5	6
4	Trash pickup	4	4
5	Gun shots	4	4
6	Trains	4	4
7	Burglar alarms	2	4
8	Auto horns	3	3
9	Chain saws	3	3
10	Hot rods–drag racing	2	2
11	Defective mufflers	1	1
	Defective pump	1	1
	Reefer truck	1	1
	Air conditioner	1	1
	Model airplanes	1	1
	Cement mix truck	1	1
	Welding equipment	1	1

SOURCE: Fidell, S. (1977) Analysis of the National Urban Noise Survey. Bolt Beranek and Newman Report 341 2. Draft submitted to U.S. EPA.

from construction activities, use of power garden equipment, and other miscellaneous sources.

The surveys have included few questions that permit an analysis of the public's perception of the relative importance of other effects of noise, such as hearing loss and property damage. Such questions should clearly be included in future surveys.

GOVERNMENT REGULATION OF NOISE

The significance of the effects of noise on the public has been recognized by Congress, many state legislatures, and various city councils. Several agencies, including the Department of Housing and Urban Development, the Department of Interior, the Department of Transportation, and the Environmental Protection Agency have been given authority by Congress to control noise within specific areas appropriate to each agency's overall charter.

There are many regulations, both in this country and abroad, designed to control noise emission of various products (U.S. EPA 1972, 1973b). In this country, aircraft noise is partly regulated by the Federal Aviation Administration (FAA) in Federal Aviation Regulation Part 36, and similar regulations have been adopted by many other nations within the International Civil Aviation Organization (ICAO). Motor vehicles, including trucks, buses, automobiles, and motorcycles, are regulated in terms of noise standards in several states and a few cities, as well as in many other nations. In addition, 43 states require that all vehicles on highways be equipped with mufflers. Snowmobiles, motor boats, and other recreational vehicles have been regulated by several states and cities, and property maintenance equipment, such as power lawn mowers, have been regulated by cities.

Equipment associated with construction noise has been regulated in several cities and in some other countries. In the United States, there are regulations limiting the total noise emanating from construction sites as well as the hours during which construction activity can proceed. Such regulations are issued by the General Services Administration for federal projects, by at least one state, and by many cities and foreign countries. External industrial noise has been regulated by many cities and towns, and, recently, power plant noise has been regulated by a few states. Many other products are regulated by local authorities, specifying the times and places that they may be used.

Although these regulations do not provide a basis for a quantitative evaluation of the major sources of noise, their existence does, in effect, constitute a listing of the products whose noise emissions are considered serious. This list is quite consistent with the conclusions of the surveys described in the previous section.

THE NOISE ENVIRONMENT

Most of the available data on levels of environmental noise in residential areas were obtained outdoors. Such data are useful in characterizing neighborhood noise, in evaluating the noise emitted by identifiable sources, and in relating the measured values to those calculated for planning purposes by theoretical noise distribution models. For these purposes, the outdoor noise data have proved more useful than information about indoor noise levels because the indoor noise levels are affected by variations from building to building in the amount of reduction in sound from outdoor levels. This variation among dwelling units is a consequence of differences in type of construction, interior furnishings, orientation of rooms relative to the noise, and the manner in which the dwelling unit is ventilated.

The range of outdoor sound levels in the United States, using the Day/Night Sound Levels (L_{dn}) index, is very large. The quiet end of the spectrum is from 20 to 45 dB for a quiet wilderness area. (This may be compared with recent estimates of the noise from rainfall, depending upon geographical location and other local factors.[2] But not all wilderness areas are quiet: a measurement approximately 25 feet from a mountain waterfall of a small canyon stream in Wyoming gave an L_{dn} of approximately 85 dB [Garland et al. 1973].) At the other end of the spectrum, sound levels of 80-90 dB are found in the most noisy urban areas, and still higher levels are found within the property boundaries of some governmental, industrial, and commercial areas not accessible to the public. The measured variation in day/night average sound levels outside dwelling units, for example, ranges from 44 dB on a farm to 89 dB outside an apartment located next to a freeway. Some examples of these data are summarized in Figure 4.2.

The sound levels inside dwellings are produced by noise generated both outside and inside the dwelling, the latter being composed of noise produced directly by human activity, appliances, and heating and ventilating equipment. In a 100-site EPA survey of urban noise (Galloway et al. 1974), the inside Day/Night Sound Level averaged 60.4

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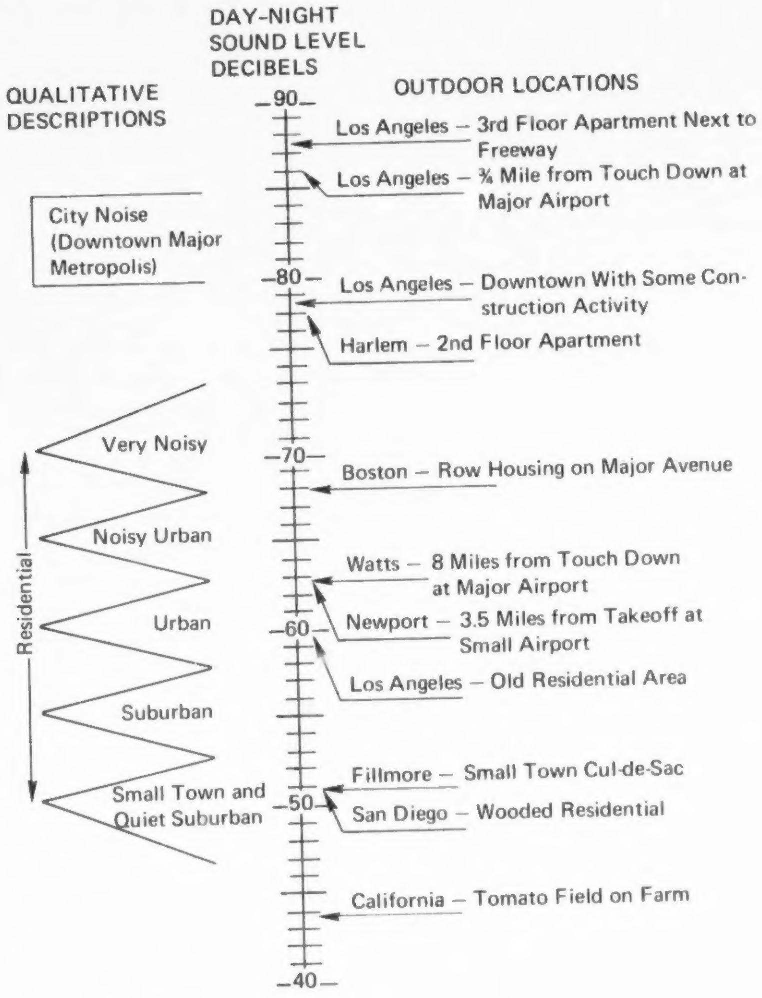
[2] Keast, D. (1976) Summer Acoustic Environment of the Jamesport and Shoreham Sites. Bolt Beranek and Newman, Inc. for Environmental Engineering, Long Island Lighting Company. BBN Report 2656. (Unpublished)

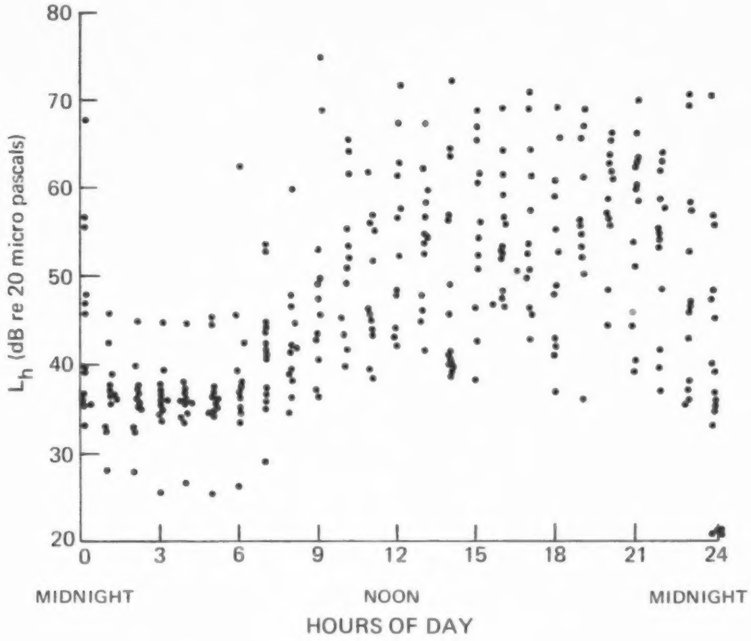


SOURCE: U.S. EPA (1974)

FIGURE 4.2 Examples of outdoor day/night sound level differentials in dB (re 20 micropascals) measured at various locations.

dB with a standard deviation of 5.9 dB while the outdoor Day/Night Sound Level averaged 58.8 dB with a standard deviation of 3.6 dB. In the survey, continuous measurements were made during a 24-hour period in 12 houses (excluding areas where significant amounts of noise were contributed by freeways and aircraft). This implies that the sounds in the homes were composed to a considerable degree of internally generated noise.

Indoor sound levels vary significantly among homes, as indicated by the data shown in Figure 4.3. The hourly equivalent sound levels reach an average minimum of approximately 36 dB during the hours between 1 a.m. and 6 a.m. This minimum level is probably governed by outdoor noise in the majority of situations. During the daytime, the hourly equivalent sound levels have a range of more than 30 dB, depending on the type of activity. Thus, during waking hours, outdoor noise sets a lower bound on indoor noise. Where the outdoor Day/Night Sound Level is



SOURCE: Galloway et al. (1974)

FIGURE 4.3 Noise inside living areas of 12 homes–values of hourly equivalent sound level as a function of hour of day.

less than 65 dB, this lower bound is significantly below the average level of internally generated noise, since the average noise reduction for houses with windows open (2 square feet of opening) is approximately 15 dB and with windows closed is 25 dB (Society for Automotive Engineers, Inc. 1971).

ESTIMATE OF THE CURRENT NATIONAL EFFECTS OF NOISE

The number of people in the country affected by environmental noise produced by mechanical equipment can be discussed in terms of six major sources of noise: urban traffic; aircraft operations; freeway traffic; construction; rail line operations; and equipment with operators and passengers. These source categories have been selected for convenience in quantification of the noise emissions and the number of persons affected by them in varying degrees. The sounds in a given area do not necessarily come from only one of these sources. For example, in some areas, urban traffic, freeway traffic, and aircraft operations each contribute more than 55 dB. Consequently, it is incorrect to estimate the number of people affected nationally by adding together the number of people affected by each source. It should also be noted that although most sources generally fall into only one of the categories, there are some exceptions. The most notable example is trucks, which contribute to noise from urban traffic, freeway traffic, and construction.

The estimated cumulative numbers of people living in urban areas in which the L_{dn} is estimated to exceed various values are summarized in Table 4.4. Some of these estimates have been reported previously (U.S. EPA 1974); the remainder were later obtained for EPA.[3]

Urban Traffic

By and large, the data confirm expectations, indicating that urban traffic is by far the most significant contributor of noise levels of intermediate intensity (L_{dn} levels of 55 dB), followed by airports and construction, which have about an equal role. However, more intense noise levels stem primarily from freeways and aircraft noise.

[3] Eldred, K. McK. and T.J. Schultz (1975) Comparison of Alternative Strategies for Identification and Regulation of Major Sources of Noise, February. Unpublished draft for the EPA.

TABLE 4.4 Estimated Cumulative Numbers[1] of People in Millions Who Live in Urban Areas Within Which the Yearly Average Day-Night Sound Level Exceeds Various Values

	Day-Night Sound Level in dB re 20 Micro Pascals					
General Source of Noise	80	75	70	65	60	55
Urban Traffic[2]	0.1	1.3	6.9	24.3	59.0	93.4
Aircraft Oper.	0.2	1.5	3.4	7.5	16.0	24.5
Freeway Traffic	0.3	0.7	1.3	2.2	3.6	5.6
Construction	–	–	0.5	2.4	8.7	26.2
Rail Line Ops	–	–	–	0.3	0.9	2.0

[1] In addition, approximately 11.5 million people may be exposed to levels in excess of $L_{eq(8)} = 75$ dB when operating various types of equipment.

[2] This estimate accounts for approximately 134 million people who live in incorporated urban areas. It does not include approximately 16 million people who live in unincorporated urban areas, nor the 40 million who live in "rural areas" not on farms but who may be exposed to highway noise.

SOURCE: U.S. EPA (1974) and chapter-footnote 3.

The estimates of people affected by urban traffic are based on a survey conducted for EPA in the summer of 1973 (Galloway et al. 1974). The survey measured the 24-hour pattern of outdoor noise at 100 sites in 14 cities, including at least one city in each of the 10 EPA regions. These data, supplemented by data from previous measurements at 30 other sites, were correlated with census tract population density in order to obtain a general relationship between L_{dn} and population size. This relationship was then used (Galloway et al. 1974), together with census data giving population in incorporated urban areas as a function of population density, to derive the national estimate in Table 4.4.

Aircraft Operations

The estimates of the number of people affected by aircraft operations have evolved during a series of studies over the past few years (U.S. EPA 1972, 1973a, 1974; U.S. Congress, Senate 1973; U.S. DOT 1971; Bishop and Simpson 1970; Bartel et al. 1974). The CARD study (U.S. DOT 1971) estimated that 1500 square miles were exposed to levels in excess of L_{dn} of 65 dB. (The aircraft noise estimates were originally calculated in terms of Noise Exposure Forecast [NEF], and have been transformed into L_{dn} with the aid of the approximate relationship: $L_{dn} = \text{NEF} + 35$ [U.S. EPA 1974].) This estimate was confirmed in the Title IV Report

(U.S. EPA 1972) by an independent assessment of the calculated contours for 27 airports (Bishop and Simpson 1970), supplemented by surveys of additional contours at several other airports. The estimate that 7.5 million people are affected by aircraft noise exceeding 65 dB (Table 4.4) was obtained by multiplying the CARD figure of 1500 square miles by the national average urban population density of 5000 people per square mile. The applicability of this figure for population density in urban areas near airports has recently been confirmed by a DOT study of 23 airports (Bartel et al. 1974). The estimates of number of people affected by maximal levels other than 65 dB were extrapolated using relationships derived in a study for the President's Aviation Advisory Commission (Bolt Beranek and Newman, Inc. 1972) and have already been reported partially in several EPA documents (U.S. EPA 1973a, 1974; U.S. Congress, Senate 1973).

Freeway Traffic

The estimates of the number of people affected by noise from freeway traffic are a revision of earlier estimates (U.S. EPA 1972, 1973a, 1974) based on L_{dn} contours for a typical urban freeway, calculated in accord with the new model of freeway noise constructed for the Highway Research Board.[4] The number of people estimated to live within various L_{dn} contours was calculated on the basis of the 8000 miles of urban freeway in the United States and the average urban population density of 5000 people per square mile.

Construction

The estimates of the number of people affected by construction noise are based on the analysis of construction site noise in the Title IV Report (U.S. EPA 1972, Bolt Beranek and Newman, Inc. 1971a), together with an updated data base recently accumulated for EPA.[5] The analysis deals with several types of construction sites, the mix of sources and the duration of operations, the surrounding population densities, and other factors appropriate to each type of site.

[4] Kugler, B.A., D.E. Commins, and W.J. Galloway (1974) Design Guide for Highway Noise Prediction and Control. Bolt Beranek and Newman, Inc. report for National Cooperative Highway Research Program Project 3-7/3.

[5] Patterson, W.M., R.A. Ely, and S.M. Swanson (1974) Regulation of Construction Activity Noise. Bolt Beranek and Newman, Inc. for Office of Noise Abatement and Control, U.S. Environmental Protection Agency. BBN Report 2887. EPA Contract 68-01-1547.

TABLE 4.5 Summary of Approximate Impact for Operators and Passengers in Nonoccupational Situations

Source	A-Weighted Sound Level (dB)		Estimated Annual[2] Exposure (Hours)	8 Hour Equivalent Sound Level in dB		Average Fractional Impact[3] Re L_{eq} (8) = 75		Approximate Number of People Exposed (Million)	Noise Impact[4] Units Re L_{eq} (8) = 75 (Million)
	Avg.[1]	Max.		Avg.	Max.	Avg. Level	Max. Level		
Snowmobile	108	112	200	96	100	2.1	2.5	1.6	3.4
Motorcycle	95	110	250	84	99	.9	2.4	3.0	2.7
Motorboat (>45 HP)	95	105	100	80	90	.5	1.5	4.4	2.2
Chain saw	100	110	20	78	88	.3	1.3	2.5	.8
General aviation aircraft	90	103	100	75	88	0	1.3	.3	0
Light utility helicopter	94	100	20	72	78	0	.3	.05	0
Trucks, personal use	85	100	180	73	88	0	1.3	5.0	0
Subways	80	93	400	71	84	0	.9	2.15	0
City buses	82	90	250	71	79	0	.4	11.0	0
Commercial propellor aircraft	88	100	50	70	82	0	.7	5.0	0
Lawn care (int. comb.)	87	95	50	69	81	0	.6	23.0	0
School bus	82	86	125	68	72	0	0	24.0	0
Home shop tools	85	98	30	65	78	0	.3	13.0	0
Highway bus	82	90	50	64	72	0	0	2.0	0
Automobile	68	90	300	58	80	0	.5	100.0	0

[1] Avg. is median of group of available measures on various products.

[2] Year of 8 hour days has 2920 hours.

[3] Fractional impact based on 10 percent dB in excess of identified level of L_{eq} (8) = 75 dB.

[4] Noise impact units calculated for average sound level. Actual impact may be greater depending upon correlation of distribution of individual annual exposures with sound level of sources.

SOURCE: Principal data source is U.S. EPA (1972).

Rail Lines

The estimates of the number of people affected by the noise of rail line operations are based on the noise levels for locomotives and freight cars calculated by EPA.[6] These levels are used to derive L_{dn} contours for the estimated average urban main-line operation of 6 trains per 24 hours (2 at night) of a national average train that is assumed to consist of 2 locomotives and 40 loaded freight cars traveling at a speed of 33 miles per hour. The number of people estimated to live between various L_{dn} contours is based on the assumption that there are 8000 miles of main lines in urban areas and that the population density near railroad tracks is 2500 people per square mile, one-half the urban average.[7]

In addition to the sources of noise listed in Table 4.4 there are many sources of noise such as snowmobiles, chain saws, lawn mowers, and the like that can produce sound levels sufficient to threaten hearing loss if exposure is sufficiently long. The estimated noise characteristics, average annual exposure, and number of people exposed to many of these sources is summarized in Table 4.5.

EQUIVALENT NOISE IMPACT

The total effect of environmental noise can be described in terms of two variables: extensity and intensity. Extensity of effect is measured by the number of people affected. Intensity, or severity, is measured in terms of the level of the environmental noise. The relationship between these elements is portrayed in Table 4.4 in which the number of people are tabulated as a function of noise level.

For various analytical purposes, it is desirable to obtain a single number indicating the total noise effect in a specific situation. Such a number permits one to describe the effect of some increment in emissions in terms of the percentage changes in the index from its initial value, rather than having to use a multiplicity of numbers to characterize each situation.

This has recently led to the design of a measurement procedure called the equivalent noise impact (ENI) analysis. This method characterizes the intensity of the effect of a sound by what is referred to as its fractional impact (FI), which is determined by multiplying a constant by the number of decibels by which the level of environmental noise exceeds the

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[6] Bender, E.K., R. Ely, M. Rudd, S. Swanson, and G. Fax (1973) Contribution to Background Document for Rail Carrier Noise Regulations. Submitted to Environmental Protection Agency, 5 December. (Unpublished)

[7] See note 6 above.

TABLE 4.6 Summary of the Estimated Noise Impact Expressed as a Percentage of the Current National Total Impact for Various General Sources of Noise, and for Noise Reduction of 5, 10, and 15 dB

		Effect of Average Noise Reduction of		
General Source of Noise	Current	5 dB	10 dB	15 dB
Urban traffic	57.0	25.5	8.57	2.14
Aircraft operations	16.8	8.5	3.62	1.48
Freeway traffic	4.45	2.60	1.42	0.67
Construction	5.9	0.89	0.016	–
Rail line operations	0.98	0.33	0.066	–
Equipment with operator/passenger	14.8	6.26	2.89	1.58
Total percentage of current impact	100	45	17	6
% Reduction from current impact	0	55	83	94

appropriate base level given in the EPA "Levels Document" (U.S. EPA 1974). The three levels that are significant for this discussion are:

1. A Day/Night Sound Level (L_{dn}) of 55 dB, for outdoor noise in residential areas with outdoor spaces (a level that produces activity interference);
2. A yearly average sound level for 8 hours (L_{eq} [8]) of 75 dB, for individual exposure to noise (a level that threatens hearing loss); and
3. A yearly average Day/Night Sound Level (L_{dn}) of 45 dB, for noises generated within residences.

The FI constants used in this report are: 0.05 for effects that involve activity interference, annoyance, and so on, and 0.10 for effects that involve direct risk of hearing damage.

Partial effects (FI_iP_i) are evaluated by multiplying the number of people exposed to each level of environmental noise by the FI_i corresponding to that noise level. The total ENI is then determined by summing the individual partial effects on all the people affected.

To facilitate comparison of alternative regulatory targets, the current total national noise level, as calculated by ENI analysis, has been chosen on a base and its value set equal to 100 percent. The percent of the total that is now contributed by each major type of source is indicated in Table 4.6, in the column labeled "current." These contribution figures are generally consistent with those reported in the previous section: they indicate urban traffic as the single most important source, outweighing all others together. It is followed by aircraft operation, which contributes some 17 percent of the total. However, in this calculation, construction falls far below aircraft operation as a contributor of noise. Indeed, third place is now taken by equipment with an operator/passenger, such as motorcycles.

Table 4.6 also provides evaluations of the consequences of reductions of 5, 10, or 15 dB in the average noise emitted by each source. For example, it indicates that a reduction of 5 dB from all pertinent sources would reduce the total effect to 45 percent of its current level; that is, it would produce a reduction of 55 percent. Similarly, a reduction of 10 dB would reduce the total impact to only 17 percent of its current value, a reduction of 83 percent.

It should be noted that the method used in this calcuation is based on the available correlations between cumulative noise levels and annoyance. These measures appear to correspond reasonably well to the evidence on annoyance from general sources of noise (for instance, airports and highways), but they may not give sufficient weight to the annoyance resulting from infrequent intrusive sounds such as those caused by motorcycles, power lawn mowers, and barking dogs. Therefore, it would be preferable if the approach were modified to take explicit account of infrequent intrusive sounds before the results are used in the design of any comprehensive noise abatement program.

INDIVIDUAL SOURCES OF NOISE

An evaluation of the prospective effects of any program of noise control must consider the contribution of each individual type of noise source. For example, an analysis of a program of urban noise control must consider the contribution of trucks, buses, automobiles, and motorcycles. This must take into account their proportions in urban traffic and their mode of operation in an urban setting. Similarly, evaluation of a program of freeway noise control must take account of the differences in the mix and the mode of operation of various types of vehicles.

One way to rank the various sources in order of their noise emissions is to estimate their total daily A-weighted sound energy for the relevant mode of operation. Although this estimate is necessarily crude, it provides an indication of the order of the sources of noise. The A-weighted daily total sound energy of a group of sources may be calculated by multiplying the A-weighted sound level emitted by each source by the number of hours it operates daily and adding the contributions of all sources. An approximate calculation of this type was provided in an EPA Report to Congress (U.S. EPA 1972) for many of the

TABLE 4.7 Sources of A-Weighted Daily Total Sound Energy Greater than 20 kW hr/day (Excluding Industrial Plants, Building Air Conditioners, Warning Devices)

Sources	kW-Hr/Day
Medium and heavy highway trucks	5,800
Aircraft (nonmilitary)	4,860
Locomotives	1,330
Sports cars	1,150
Passenger automobiles	800
Light duty trucks	570
Motorcycles (off road)	500
Motorcycles (highway)	325
Construction trucks	296
Snowmobiles	160
Air compressors	147
Concrete mixers	111
Jack hammers	84
Scrapers	79
Dozers	78
Pavers	75
Generators	65
Lawn mowers	63
Garden tractors	63
Pile drivers	62
Rock drills	53
Inboard motor boats	52
Construction pumps	47
Outboard motor boats	42
Chain saws	40
Snow blowers	40
Pneumatic tools	36
Backhoe tractors	33
Derrick cranes	28
Railroad freight cars	25
Graders	25
Buses (city & school)	20

SOURCE: Eldred, K. and W. Patterson (1973). Rationale for the Identification of Major Sources of Noise, Bolt, Beranek and Newman, Inc., BBN Report No. 2636, September. Draft submitted to U.S. EPA.

sources of noise considered in the report. The calculation was based on the average A-weighted sound level at a fixed distance from the source, its estimated average daily operating time, and the number of sources estimated to be operating in the United States in 1970.

These estimates have been extended to include all of the sources for which data are available (U.S. EPA 1972). The results are given in Table 4.7 for sources whose daily total sound output exceeds 20 kilowatt hours

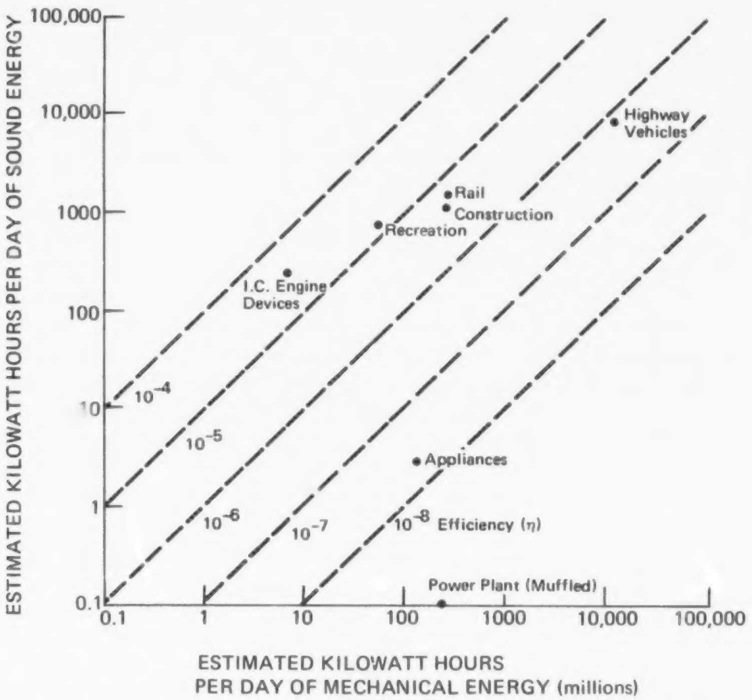
(KWh) of energy. The results show that transportation sources—road, air, and rail—produce the most sound energy per day, followed in approximate order by the noise of construction equipment, recreational vehicles, property maintenance equipment, and home appliances. This order is entirely consistent with the priorities that can be inferred from the noise regulations previously promulgated by various levels of government, both here and abroad.

To illustrate better the relationship between sound and mechanical energy, a graph of the daily sound and mechanical energy generated by various sources is displayed in Figure 4.4. The diagonal lines indicate the acoustic efficiency (n), that is, the fraction of mechanical energy that is transmitted as acoustic energy. This fraction ranges from less than one billionth (refrigerators) to an amount exceeding one thousandth (model airplane engines). The majority of sources have an efficiency of about one millionth. This is true, in particular, of highway vehicles and construction equipment powered by internal combustion engines. Sources corresponding to points above this line for highway vehicles, $n = 10^{-6}$, are not usually equipped with noise reduction devices such as mufflers or enclosures. Thus, the efficiency fraction conveys two types of information: the lower the fraction for a source, the more attention has been devoted to silencing or muffling it; the higher the fraction, the greater the likelihood that the source will generate noise. A notable example of sound reduction is provided by muffled power plants, which have reduced their sound energy output by a factor of about 40,000. Without such sound reduction, the total daily sound energy from power plants is estimated to be 3962 KWh/day, which would rank them as the third largest source of noise.

CONCLUSION

This chapter has examined the evidence on the contribution of a number of different sources of noise and has described methods that can be used in evaluating such sources. It has shown that a number of different studies consistently rank urban traffic noise as the major contributor of annoying sound with aircraft serving as a significant second source.

Most important, the chapter has confirmed the pervasive character of sound and the large number of people affected by it. Over 40 million residents of the United States seem to be disturbed by urban traffic noise and some 14 million by airplane traffic noise. More than 12 million seem to be annoyed sufficiently by sound levels in their neighborhoods to report that they are contemplating moving. Thus, noise would seem clearly to be imposing a very real and very substantial cost upon American society.



SOURCE: Eldred, K. and W. Patterson (1973). Rationale for the Identification of Major Sources of Noise, Bolt, Beranek and Newman, Inc., BBN Report No. 2636, September. Draft submitted to U.S. EPA.

FIGURE 4.4 Comparison of the daily total sound energy and daily total mechanical energy of selected classes of sources.

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5

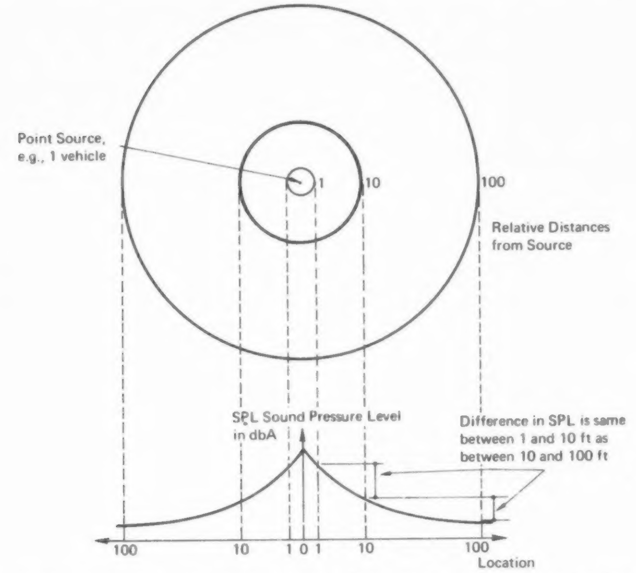
Projections of Transportation Activity

INTRODUCTION

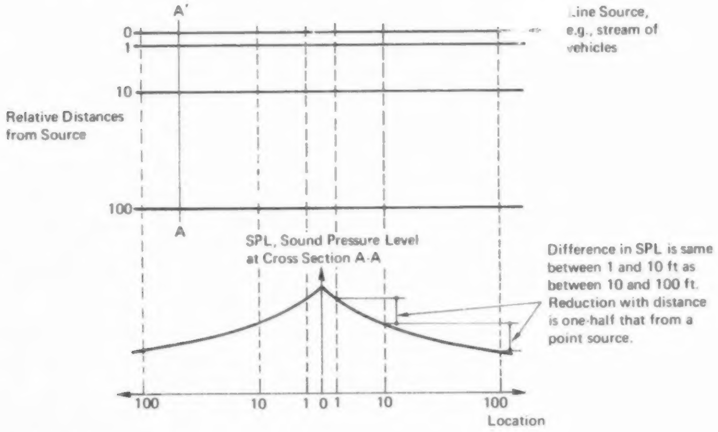
Today, transportation is one of the most pervasive sources of noise. Projections into the future suggest significant increases in most forms of transportion activity: by 1985 there may be more than 430 million aircraft operations per year compared with 80 million today, 130 million autos in use compared with 84 million today, and 28 million trucks as compared with 17 million today. Although the use of public transportation is expected to increase, its share in overall transportation may increase by only about 1 percent because of a concomitant growth in vehicle miles traveled, primarily by auto. While the increase in the level of noise emanating from each transportation source (using existing facilities—equipment, roads, etc.) could be expected to rise about 3 dB for each doubling of its transportation operations, the rise in noise levels will, in fact, be less than 3 dB since new equipment, already affected by current noise regulations, is quieter than that currently in use.

The magnitude of the social cost of transportion noise depends on the amount of noise from other sources (which may mask the transportion noise or accentuate it), the characteristics of the noise path, and the recipient. Thus, the particular conditions under which a sound is generated and received can determine how detrimental transportation noise will be.

Figure 5.1 shows how path and transmission characteristics affect a sound. Noise can be reduced by (1) reducing the amount generated or


Point Source,
e.g., 1 vehicle
1
10
100
Relative Distances
from Source
SPL Sound Pressure Level
in dbA
Difference in SPL is same
between 1 and 10 ft as
between 10 and 100 ft
100
10
1
0
1
10
100
Location

a. Noise attenuation with distance from a point source, such as an individual, isolated vehicle.


A'
0
1
10
100
Line Source,
e.g., stream of
vehicles
Relative Distances
from Source
A
SPL, Sound Pressure Level
at Cross Section A-A
Difference in SPL is same
between 1 and 10 ft as
between 10 and 100 ft.
Reduction with distance
is one-half that from a
point source.
100
10
1
0
1
10
100
Location

NOTE: Not drawn to scale.

b. Noise attenuation with distance from a line source such as a stream of vehicles.

FIGURE 5.1 Noise attenuation.

emitted (e.g., truck mufflers), (2) increasing the length of the path (e.g., locating an airport away from residences), or (3) creating path characteristics that reduce transmission (e.g., tunnelling of the transit system or installation of sound barriers or building insulation).

TRAFFIC NOISE

Today, more people are affected by highway and street vehicular noise than by noise from any other source, and this noise grows directly as the number of vehicle registrations, miles of road, and average speeds increase. If crowded roadways or national speed limits lower average speeds, and especially the very high ones, the associated noise will also decrease.

Although programs for the reduction of noise on new facilities are being planned and carried out by federal, state, and local agencies and are likely to be at least moderately successful in reducing highway noise, much of the troublesome traffic noise is generated on local residential streets. While it is possible to design programs to reduce noise on such streets—by rerouting traffic, controlling speed limits and traffic flow conditions, regulating truck routes, and so on—it is difficult. The manipulation of traffic flows as a means to reduce the effects of noise is limited by the pervasiveness of local traffic and the comparatively small number of routes that are both noise-tolerant and suitable for use, given the purposes, origins, and destinations of trips. In addition, measures to reduce traffic noise have to be balanced with their economic effects upon the community and the desire for mobility.[1]

Figure 5.2 shows the cumulative distribution of traffic noise, measured 50 feet from the edge of a roadway, by type of vehicle. In addition to variation by type of vehicle, vehicle noise can also vary drastically with mode of operation. The difference between the noise made by a cruising auto and an auto accelerating at open throttle can be 7 to 15 dB. Removal or modification of noise control equipment can increase the noise level further by some 10 or 20 dB. In addition, the type of tires or vehicle can affect the sound level produced by 5 to 10 dB. Figure 5.3 is a nomograph for calculating one index of expected noise level—L_{10}, the level exceeded 10 percent of the time—as a function of several of these factors.

At present, the greatest single source of highway noise is trucks, primarily large vans and trailer trucks used in interstate commerce. The average heavy truck cruising at 45 mph produces approximately 86 dB(A)

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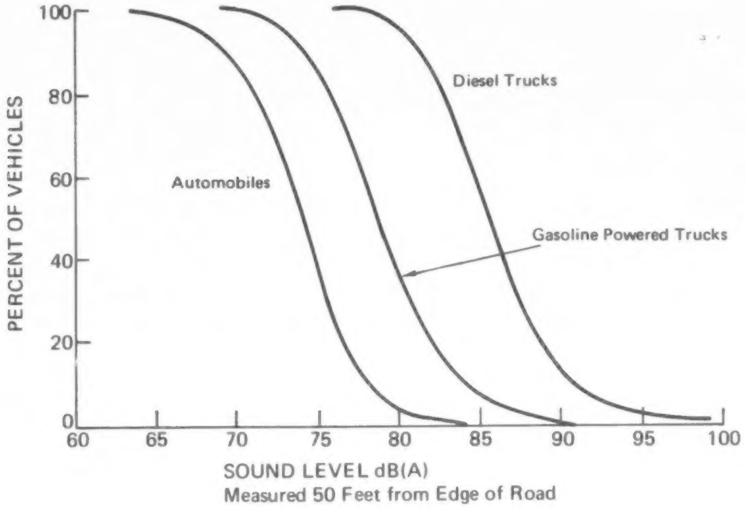
[1] Mosbaek, E.J., J.P. Goodrow, and W.C. Kester (1975) Policy and Techniques for Highway Noise Valuation and Compensation. Jack Faucett Associates, Inc. report for National Cooperative Highway Research Program Project 11-6.

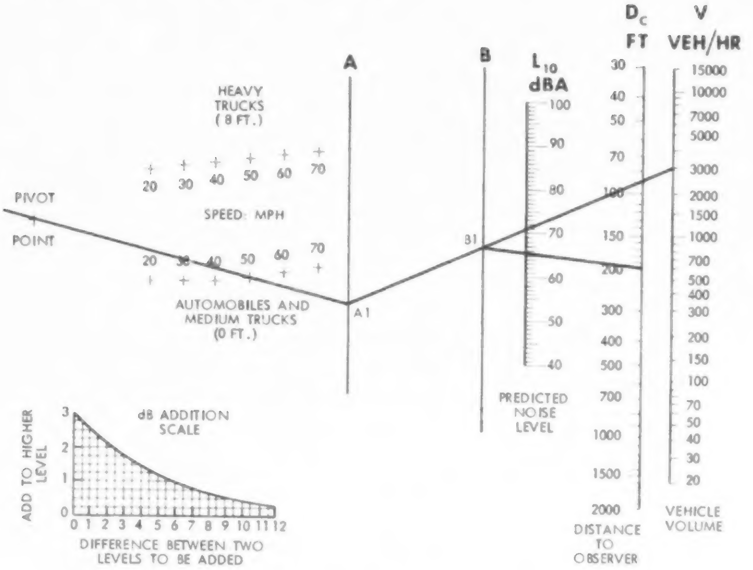


SOURCE: U.S. DOT (1973:10)

FIGURE 5.2 Cumulative distribution of highway vehicles versus noise level.

at 50 feet, although levels above 94 dB(A) are not uncommon. Acceleration produces 5 dB(A) more than cruising, and an additional 2 dB(A) is generated on a 3-5 percent upgrade. At lower highway speeds, where engine exhaust noise is dominant, mufflers can reduce truck noise to approximately 78 dB(A). At higher speeds, tire/pavement noise predominates, as shown in Figure 5.4. New rib tires make the least noise, while pocket retreads are noisiest, and old, worn tires are noisier than new ones for each class. Therefore, regulation of the type and maintenance of tires can be an effective means to reduce truck noise.

Another important determinant of road noise is the spacing of vehicles. Noise from individual vehicles diminishes at a rate of 6 dB for each doubling of distance. However, a line of closely spaced vehicles produces both a higher noise level and a diminution rate of only 3 dB for each doubling of distance. For most highway and urban traffic situations, the line source model, as illustrated in Figure 5.1b, is the appropriate one. However, for single intrusive events, such as an individual motorcycle or


HEAVY TRUCKS (8 FT.)
20 30 40 50 60 70
PIVOT
SPEED: MPH
POINT
20 30 40 50 60 70
AUTOMOBILES AND MEDIUM TRUCKS (0 FT.)
A
A1
B
B1
L_{10} dBA
100
90
80
70
60
50
40
PREDICTED NOISE LEVEL
D_C FT
30
40
50
70
100
150
200
300
400
500
700
1000
1500
2000
DISTANCE TO OBSERVER
V VEH/HR
15000
10000
7000
5000
3000
2000
1500
1000
700
500
400
300
200
150
100
70
50
40
30
20
VEHICLE VOLUME
dB ADDITION SCALE
ADD TO HIGHER LEVEL
0
1
2
3
0 1 2 3 4 5 6 7 8 9 10 11 12
DIFFERENCE BETWEEN TWO LEVELS TO BE ADDED

Instructions and Example of the Use of the Nomograph

1. Automobiles: Extend a line from the pivot point through index below the pivot point representing the speed of the traffic flow to vertical line A. Connect that intersection on A (e.g. A1) with the appropriate vehicle volume and note where vertical line B is intersected (e.g. B1). Connect the intersection on B with the distance to the observer, and read the predicted L_{10} from the scale. In the example shown, if automobiles are traveling at 50 mph at a volume of 3000 cars per hour, an observer 200 feet from the flow would be exposed to an L_{10} of 66 dBA.

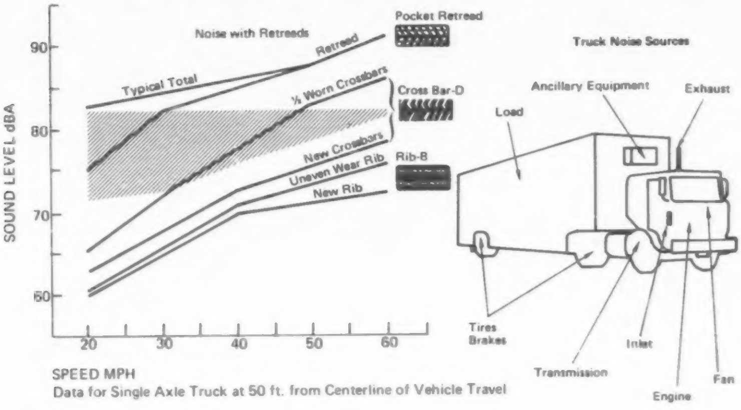
2. Medium trucks: Proceed as with automobiles for the first step, but multiply the volume by 10 for use in the nomograph. Thus, the example shown also corresponds to medium trucks traveling 50 mph at a vehicle volume of 300 trucks per hour with the observer at 200 feet from the traffic line.

If the medium trucks and automobiles are traveling at the same speed, their volumes can be combined. The example could be used for a vehicle volume of 2000 automobiles and 100 medium trucks per hour to yield the 3000 vehicle volume figure.

3. Heavy trucks: The estimation of noise from heavy trucks is performed in similar fashion except that the speed indices to be used are above the pivot point. If the L_{10} for heavy trucks is to be combined with that for medium trucks and automobiles, the dB addition scale in the corner of the figure should be used.

SOURCE: NRC (1977) Highway Noise-A Design Guide for Prediction and Control. Transportation Research Board, National Cooperative Highway Research Program Report 174. Washington, D.C.: To be published by the National Academy of Sciences in 1977.

FIGURE 5.3 Nomograph for estimating traffic noise as a function of type of vehicle, speed of traffic, traffic density, and distance from the roadway.



SOURCE: U.S. DOT (1973)

FIGURE 5.4 Relative level of engine noise compared to levels of various types of tires.

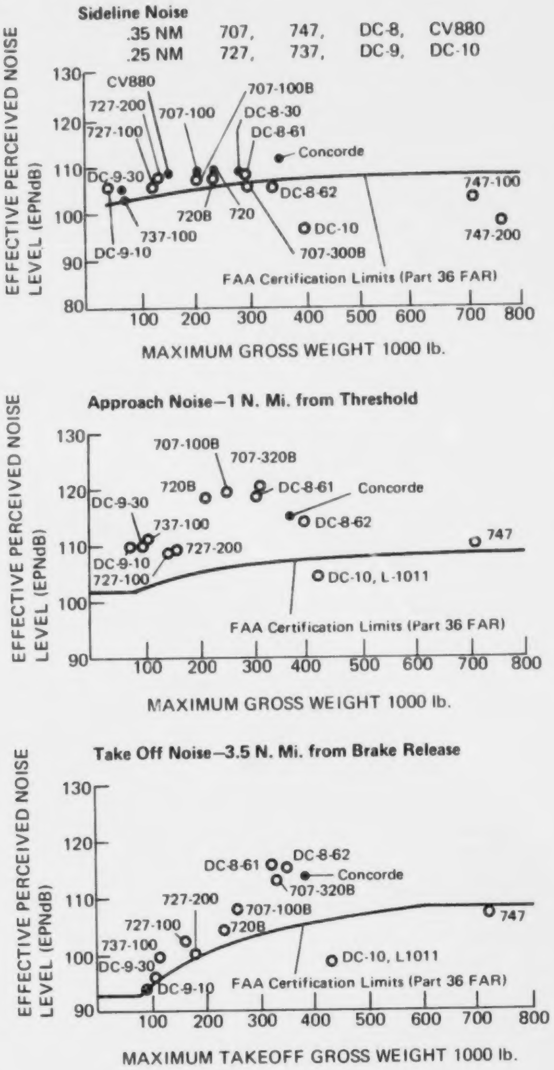
garbage truck, the point source model, as illustrated in Figure 5.1a, is applicable.

AIRCRAFT NOISE

Aircraft noise, though it affects fewer people than traffic noise, generally has a more intense effect on people under air routes in close proximity to airports. Figure 5.5 portrays noise levels from the operations of a variety of jet aircraft in current use. New facilities, using careful airport site selection and design, compatible zoning, buffer zones, and noise barriers, can significantly reduce the effects of aircraft noise. For existing facilities, land use controls, buffer zones, and barriers may also be useful, but it will probably be more costly and more difficult for them to be adopted. Aircraft noise will be a growing problem at small airports as the use of private jets and general aviation increases, and current growth patterns are likely to make it difficult to implement local controls.

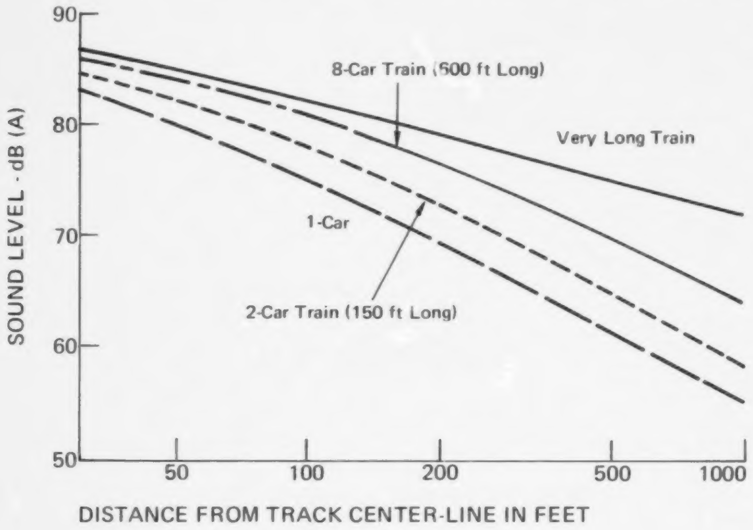
RAIL NOISE

Rail transit systems are another source of noise, but one for which there has been significant progress in abatement. Welded rail can provide an improvement of 6 dB(A) or more over bolted rail sections; rail and wheel maintenance can yield another 5-dB improvement. Larger radius turns



SOURCE: U.S. DOT (1973)

FIGURE 5.5 Current aircraft noise levels.



SOURCE: U.S. DOT (1973)

FIGURE 5.6 Wayside noise level for transit trains of various lengths at 40 mph.

can make a major contribution by reducing flange squeal. Finally, improved drive systems can reduce noise 5-8 dB at high speeds.

Older systems, which often lack these amenities, are gradually being replaced or upgraded. However, proper maintenance of new systems is crucial to prevent significant increases in noise. Rail systems generally present an excellent opportunity for the use of sound barriers close to the vehicles. Noise barriers installed along the right of way will reduce noise levels by 10-12 dB at 50 feet and by 7-8 dB at up to 500 feet.

Figure 5.6 illustrates the behavior of train-generated noise levels as a function of distance from the centerline. The increase in noise levels resulting from multiplicity of cars is accentuated with distance. Thus, noise from a one-car train will attenuate at a rate of 6 dB with a doubling of distance, but only at a rate of 3 dB with doubling of distance if the train is long.

FUTURE TRANSPORTATION NOISE

GENERAL CONSIDERATIONS

Three important issues must be dealt with in any general discussion of the noise problems that can be expected from transportation: (1) one must determine which transportation activities (or modes) and locational or environmental situations are most likely, initially, to constitute noise problems; (2) one must estimate the extent to which changes in patterns of transportation use will alter the number and magnitude of these problems; and (3) one must consider any changes in transportation technology, system operations, etc., that are likely to alter the nature or magnitude of these problems.

LIKELY SOURCES OF NOISE PROBLEMS

With reference to the first issue, it is difficult to specify with certainty what circumstances will create noise problems because so much depends on the subjective feelings of recipients rather than on any directly observable physical or psychological danger to recipients. (There are only a few exceptions—such as in extremely noisy subways, and in the vicinity of airports.) In general, however, one can say:

> While there are many important sources of intrusive noise, transportation vehicle noise tends to dominate most residential areas. In fact, the cumulative effect of the increase in noise intrusion by transportation vehicles is, to a large extent, responsible for the current general concern with noise (U.S. Congress, Senate 1972).

Some of the ways of measuring the effects of transportation noise on the community are discussed in Chapter 4. Obviously, more noise energy will be produced by those modes of transportation that generate higher noise levels, are more numerous, or operate for more hours. Table 4.7 in Chapter 4 summarizes this information; Table 5.1 presents it in somewhat different form. Another measure is the contribution to the residential noise level—nonidentifiable community background noise—which is summarized in Table 4.6 in Chapter 4. Still another measure can be made by estimating the noise levels produced by a single intruding event for each kind of transportation aircraft and vehicle. This information is given in Table 5.2, together with information on the size of the fleet in 1970.

TABLE 5.1 Relative Noise Energy by Modes of Transportation

Major Category[1] Specific Mode	Noise Energy[2] (Kilowatt-hours/day)	Percent of Total[3]
Aircraft		
4-engine turbo fan	3,800	27.6
2 and 3 engine turbo fan	730	5.3
General aviation	125	0.9
Helicopters	25	0.2
Sub-total	4,680	34.0
Highway Vehicles		
Medium and heavy trucks	5,000	36.4
Sports cars, imports and compacts	1,000	7.1
Passenger cars (standard)	800	5.8
Light trucks and pickups	500	3.6
Motorcycles	500	3.6
City and school buses	20	0.1
Highway buses	12	0.1
Sub-total	7,832	57.0
Railroad Vehicles		
Locomotives	1,200	8.7
Freight trains	25	0.2
High-speed intercity passenger trains	8	0.1
Standard passenger trains	1	<0.1
Sub-total	1,234	9.0
Urban Rail		
Rail rapid transit	6	<0.1
Pre-WWII trolleys	1	<0.1
Post-WWII trolleys	<0.1	<0.1
Sub-total	7	0.1
TOTAL	13,750	100.1

[1] Top ten categories that each generate at least 125 kWh per day.

[2] Rounded to nearest unit.

[3] Totals may not add due to rounding.

NOTE: This table duplicates some of the information presented in Table 4.7; it is based on an earlier, slightly different set of data.

SOURCE: U.S. Congress, Senate (1972), pp. 2-47 to 2-80.

TABLE 5.2 Typical Noise Levels by Kind of Vehicle and Aircraft

Major Category Specific Vehicle or Aircraft	Range of Typical Noise Level (dBA at 50 feet)	Fleet Size in 1970 (Vehicles)
Aircraft		
2-3 engine turbo-fan	85-100[1]	1,174
4 engine turbo-fan	94-105[1]	815
4 engine turbo-fan (wide body)	92-103[1]	79
3 engine turbo-fan (wide body)	84-95[1]	–
V/STOL		
Light helicopters	65-86[2]	2,900
Medium helicopters	76-88[2]	320
Heavy helicopters	82-92[2]	40
STOL aircraft	83[3]	–
General Aviation		
Small engine prop	67-90[1]	110,500
Multi-engine prop	70-93[1]	17,500
Executive jet	81-97[1]	900
Highway Vehicles		
Automobiles		87,000,000
Standard	64-76	
Sports, imports, compacts	70-87	
Trucks		19,000,000
Light	70-85	
Medium	80-89	
Heavy	85-95	
Buses		400,000
City and School	70-85	
Highway	75-87	
Motorcycles	64-95	NA[4]
Railroad Vehicles		
Locomotives	88-98	27,000
Freight cars	80-94	NA[4]
Passenger cars	80-90	1,000
Urban Rail		
Rail rapid transit	82-95	NA[4]
Trolley	68-80	NA[4]

[1] At 1,000 feet.
[2] At 500 feet.
[3] Proposed limit.
[4] Not available

SOURCE: U.S. Congress, Senate (1972)

EXPECTED TRENDS IN TRANSPORTATION USE

The second issue that must be dealt with in formulating projections of transportation noise is calculated growth trends for transportation activities. The U.S. Department of Transportation has produced transportation activity projections up to 1980, based on expected economic growth as estimated by the Interagency Economic Growth Project (IEGP). The determinants of activity are assumed to be population, income, location patterns, price of transportation, and quality of transportation. The DOT and IEGP assumptions about future values of these parameters can be summarized as follows:

> The population of the U.S. is expected to grow from 205 million in 1970 to 228 million in 1980 and 255 million in 1990. Income is expected to grow at an average annual rate of 4.3 percent per year through 1980 and 4.1 percent per year through 1990. Location patterns will continue to favor the use of the private automobile in intracity travel, while the decline of agriculture and the self-sufficiency of large metropolitan areas will tend to dampen some aspects of intercity freight growth. Continued depletion of our supply of fossil fuel and the costs of satisfying ecological considerations will exert upward pressure on transportation prices. The quality of transportation between now and 1990 is expected to improve in all modes; it will be determined in large part by public policy decisions (U.S. Transportation Department 1972).

The DOT estimates of future transportation activity based on these assumptions are reported in Table 5.3 for passenger travel and in Table 5.4 for freight transportation. These tables also include estimated ranges of activity in 1980, based on a revised version of the original DOT data. Figure 5.7 is a graphic representation of indices of GNP, population, and aggregate freight and passenger transportation expenditures. The growth estimates are based on data from 1972 and earlier and results in estimates near the upper bound for most transportation activities.

PROJECTED PATTERNS OF TRANSPOPTATION USE AND NOISE

One conclusion implied by the discussion in Chapter 4 is that an abatement program for transportation noise should focus on airports, freeways, and high-speed arterials (especially those with significant amounts of truck traffic). That conclusion and the projected patterns of transportation activity described in the preceding section permit us to draw a number of conclusions about projections of transportation noise.

Aviation

The number of domestic passenger-miles is expected to exceed, and perhaps even double, its current level by 1980 and to double again by 1990. The increase in the number of operations will reflect this growth. International travel will triple, and then double, in the same periods. In the original estimates, hours flown in general aviation were expected to double by 1980 then to increase by 60 percent in the following decade; the subsequent revision of these estimates drastically reduced the rate of increase to something above 40 percent by 1980. We can only conclude that the importance of passenger aviation as a contributing factor to noise will increase in the future.

Freight aviation will also become more important. The number of ton-miles carried by domestic air freight is expected to increase by a factor of 3.5 by 1980 and by an additional factor of 2.5 by 1990.

The number of airports is expected to remain about the same. If the number of flights increases proportionately to passengers, the noise problem will increase but by a smaller proportion because the increase in average aircraft size will probably not be by so much as to absorb completely the additional passengers. Generally, it is unlikely that any other carriers will be able to divert any substantial amount of air traffic, although highly improved ground transportation may be able to do so along high density routes such as the Northeast Corridor.

Automobile Travel

Total passenger auto vehicle-miles are forecast to increase by between 48 and 107 percent by 1980 and by an additional 32 to 46 percent by 1990. Although there is wide variation in these estimates and it is likely that the actual values will lie toward the lower end of these ranges, the increase will still be significant.

Auto travel may be held in check by a sharp rise in the cost of driving, such as may result from an increase in the price of fuel or increased taxes (which may be levied for any number of reasons—from the desire to add to general revenue to specific purposes such as road maintenance or public transit subsidy). There is little information on the effectiveness of price increases in reducing the number or length of trips or in inducing car-pooling or the use of public transit.

The U.S. Federal Highway Administration (1974) in DOT has produced some estimates in studying various influences that may affect their estimates of highway travel.

TABLE 5.3 Trends and Projections: Passenger Travel 1980

				1980[1]		
Component	Unit of Measure	1965	1970	a	b	1990
GNP	$billions 1969 constant	787.1	936.4	1481.0		2095.9
Population	millions	194.6	205.2	227.5		254.7
Aviation						
Domestic	billions pax-miles	57.9	110.2	258.5	231.4-278.1	523.2
International	billions pax-miles	12.6	25.4	79.8	67.2- 89.1	180.4
General	millions hours flown	15.4	25.1	53.9	34.9[2]	83.2
Railroads	billions pax-miles	17.6	10.8	8.6	8.2- 8.6	10.2
Auto						
Business	billion VMTs	113.5	138.2	231.2	212.6-247.9	323.4
Personal	billion VMTs	609.7	748.3	1082	1108-1271	1439.7
Bus	billion pax-miles	23.8	25.4	27.0	23.3- 29.2	27.8
Urban Transit	billion pax	6.8	6.1	7.5	7.0- 7.7	9.1

[1] Left-hand column under 1980 shows figures based on original projections. Right-hand column shows figures based on revised projections; range of final demand growth is from 3.5-5.0 percent per year.

[2] 4.3 percent annual growth rate of final demand.

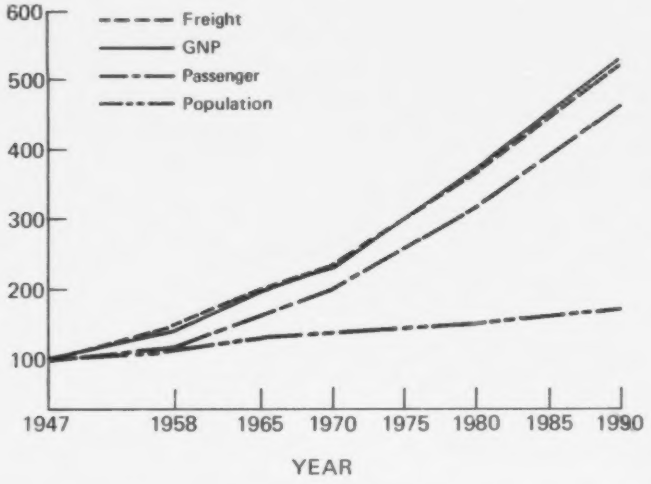
SOURCE: U.S. Transportation Department (1972) and Jack Faucett Associates (1973)

TABLE 5.4 Trends and Projections: Freight Transport

Component	Unit of Measure	1965	1970	1980		1990
				a	b	
GNP	$billions 1969 constant	787.1	936.4	1481.0		2095.9
Population	millions	194.6	205.2	227.5		254.7
Aviation						
Domestic	billion ton-miles	2.0	3.9	14.0	13- 15.5	33.37
International	billion ton-miles					
Railroads	billion ton-miles	704.5	740.0	966.6	890-1050	1223.1
Truck						
For hire						
Intercity	billion ton-miles	154.0	195.6	325.2	299.3-322.6	458.7
Local	billion ton-miles	7.9	9.7	15.[illegible]	14.5- 16.8	21.5
Private						
Intercity	billion ton-miles	110.8	132.0	212.1	194.1-225.9	299.7
Local	billion ton-miles	63.9	74.3	117.8	108.0-125.2	165.1
Total Private	billion VMTs				51.2- 62.1	
Intercity	billion VMTs	15.8	18.8	30.6	28.0- 32.6	42.2
Local	billion VMTs	18.9	21.1	35.3	32.3- 37.5	48.0
Domestic water	billion ton-miles	506.3	586.3	810.5	741-874	1041.7
Pipeline	billion ton-miles	339.0	403.1	614.0	569.4-665.1	851.8

See note[1], T 5.3

SOURCE: U.S. Transportation Department (1972) and Jack Faucett Associates (1973)



SOURCE: U.S. Transportation Department (1972:93)

FIGURE 5.7 Index of growth (1947–100).

Price of gasoline. Price elasticity of demand for gasoline is estimated to be about -0.278. If this point estimate is applicable to large changes, a 100-percent increase in gasoline price would result in a 7- to 14-percent reduction in vehicle miles traveled.

Characteristics of trip (by type). The various types of trips may exhibit the following relationships:

(1) A 20-percent decrease in auto shopping would result in a 1.5-percent decrease in vehicle miles traveled.

(2) A 20-percent decrease in social and recreational trips would result in a 6.5-percent decrease in vehicle miles traveled.

(3) A 20-percent decrease in work trips would result in a 7-percent reduction in vehicle miles traveled. However, work and related business trips (which total 42 percent of vehicle miles traveled) are assumed to be nondiscretionary and relatively inelastic.

Auto Occupancy. An increase of 50 percent in auto occupancy for work trips to central business districts (CBD) would result in a 1-percent decrease in vehicle miles traveled in metropolitan areas. A similar occupancy increase in non-CBD work trips would result in a 12-percent reduction in metropolitan vehicle miles traveled.

Transit Improvement. Express bus operations to central business districts (such as those on Shirley Highway, from suburban Virginia to downtown Washington, D.C.) would reduce metropolitan vehicle miles traveled less than half of 1 percent.

Bicycle and Walking Trips. Since 62.5 percent of all trips (which account for 16 percent of all vehicle miles traveled) are less than 5 miles long, it has been proposed that many of these are candidates for diversion to walking or bicycle. If all trips under 2.5 miles were diverted, the total vehicle miles traveled would decrease 6 percent.

Public Transit

It is also possible that public transit can be made more attractive and that large numbers of persons will consequently be diverted from auto commuting. Current trends do not go in this direction, for many reasons, most importantly because: (1) most public transit routes in larger metropolitan areas are radial and oriented to the central business district; (2) a small fraction of all trips in such areas (typically less than 10 percent) are oriented to the central business district; and (3) a considerable fraction of such trips already involve the use of public transit. While transit service for short, dispersed trips can be improved, it is unclear whether this would lure any significant number of motorists. While there is much debate about the wisdom of national and local transit policies, it is not clear whether their directions will change.

Perhaps more can be achieved by a change in transportation policies relating to government investment, pricing, and other operating characteristics. A computer model[2] has recently been used to analyze a set of alternatives and yielded the following results:

(1) Changes in the allocation of investment between highway and public transit might produce a variation in the number of auto passengers as a percentage of total trips (the "11 modal split") by as much as 50 percent, starting from a 1972 base.

(2) A 20-percent reduction in total planned 1972-1990 investment would reduce modal split less than 3 percent.

(3) Increases in auto occupancy might increase auto passenger trips because highway congestion might be decreased.

Of course, any conclusions depend on the validity of the premises of the computer model from which they stem.

[2] Werner, E., Assessing National Urban Transportation Policy Alternatives, paper prepared for presentation at 47th National Operation Research Society of America Meeting, April-May, 1976. (Unpublished)

Truck Traffic

Highway freight traffic is expected to grow commensurately with passenger traffic. Intercity ton-miles are expected to grow 64 percent by 1980 and 41 percent from 1980 to 1990. The number of freight ton-miles on local highways is expected to grow by 60 percent by 1980 and by 40 percent from 1980 to 1990. Therefore, the highway freight carried by trucks and the noise produced by it is likely to become increasingly important nationally, and even more so in urban areas.

The future of truck traffic noise problems is quite uncertain. The major question is raised by the possibility of the use of trailers on flat cars (TOFC), known as rail piggyback service, which could replace much intercity trucking. But TOFC has not grown significantly, and most studies indicate that regulatory and institutional constraints (e.g., trucker work rules) now make TOFC economically unattractive.

POTENTIAL TECHNOLOGICAL CHANGES

Since the estimates just described are now a few years old, the obvious starting point for a reappraisal is the technological advances that have occurred since then. Foremost is the supersonic transport plane (the SST). Recent FAA tests indicate it generates more noise than conventional sub-sonic aircraft. Should it gain any wider acceptance than now appears likely, it will contribute to noise levels. In contrast, automobiles in 1977 are less noisy than their predecessors and the newer, high by-pass engine jet planes are quieter than the older jet planes.

One class of changes that may prove important are those that reduce travel. For example, a recent study for DOT (Krzyczkowski and Henneman 1974) suggests that the use of telecommunications as a substitute for travel, changes in land use patterns, and rescheduling of work activity can supplement economic disincentives to travel. The study concludes that in the short term (1-3 years), a 3-percent reduction in urban vehicle miles traveled may be achievable through rescheduling of work and travel. By 2015, a reduction of one-seventh in vehicle miles traveled (168 million per day) will be possible if the appropriate communication substitute technology (essentially video-phone and information transfer equipment) is perfected.

The DOT commissioned a study (Golding et al. 1970) similar to the one being undertaken in this chapter. The study, conducted in 1970, was a cursory survey of technological developments that are in the planning phase, in initial prototypes, or in the final stages of experimental test and design. The survey concluded that "technological changes and improvements in transportation will be evolutionary and gradual."

UNCERTAINTIES IN ESTIMATES OF TRANSPORTATION ACTIVITY

The use and heavy reliance on Department of Transportation projections of future transportation activity by mode and region within the United States is not meant to be an unqualified endorsement of those projections. Their use was predicated on the fact that they appear to be among the best of the projections that are available from public sources and that contain a full description of the methods used. There are many other projections of transportation activity, made with many different assumptions and methods; some of these are public to varying degrees, but without full disclosure of the procedures. These other projections were not included in this study because of the lack of detailed information on the assumptions or precise methods used.

Projection of future activities in transportation or other sectors of the economy is much more of an art than a science. There are numerous factors that will undoubtedly influence future transportation activity that cannot be taken into account in the projections or that can only be taken into account by modifications of the projections by human judgment. The effects of many of these factors—such as the long-term influence of the recent increases in fuel prices, in which both land use patterns and travel patterns can be modified, the adjustments presumably being in the direction of a reduced amount of travel—can only be guessed at. Future activity may also be affected by specific steps, such as rationing, taken to ameliorate the adverse effects of future embargos on oil imports. On the other hand, the development and successful marketing of small automobiles that might use considerably less oil-based fuel or might be propelled by energy sources not based on oil (such as the battery-powered electric car in which electricity is generated by coal or hydroelectric means) might considerably relax any constraints on travel, although an increase in such automobile use would probably be offset by the lowered noise emissions of smaller or electrically powered vehicles.

Government policies with respect to land development patterns can have a very significant effect on the total amount and character of transportation activities, as the suburbanization of population and employment in the past few decades has revealed. Policies that may have some very significant influence on transportation include the banning of automobiles from the central parts of cities, the adoption of traffic control technology that would significantly expand the capacity of the existing system of streets and highways, the fostering of the development of integrated intermodal transportation firms for the movement of freight, and the pricing of passenger transportation and (in particular, urban transportation) that would require the recovery of full costs from users.

ENVIRONMENTAL IMPACT STATEMENTS

On the basis of the National Environmental Policy Act of 1970 and its amendments, any project involving the expenditure of federal funds must be planned so as to minimize the damaging effects of noise and other unwanted and undesirable consequences. The specific provisions of the Act are:

These requirements have been implemented by the U.S. Department of Transportation in various ways. An environmental impact statement (EIS) must be prepared for each project which is likely to have any negative environmental effects. It must include a specification of these effects, documentation supporting the plan or design recommended as most reasonable, and an evaluation of the positive and negative impacts of the various alternatives considered. The preparation of the EIS is in addition to other requirements which call for comprehensive evaluation of the alternative means of achieving the transport objectives at all levels—plans, systems, and projects. The comprehensive evaluations include consideration of negative environmental effects, including the identification of noise as a potential problem and its effects on users of the transport system, on employees, and on the surrounding areas.

While these requirements specify that noise and other damaging effects of transportation projects are to be considered, they do not provide clear, operational guidelines for choice among the available plans or designs. They provide no guidelines on the magnitude of the expense that should be incurred to reduce detrimental effects or on the relative priority to be given to the achievement of other objectives in the attempt to abate noise. In practice, these decisions are left to the planners and engineers involved in the project, with the influence of political leaders and the public. Perhaps this assumes implicitly that their experience serves as a reasonable proxy for benefit-cost comparisons.

The expectation that noise will produce serious environmental damage has resulted in the termination of many transportation projects already in their final planning and design stages, as well as of a few in which initial construction had begun. This suggests that the earlier environmental review process and the associated decision-making calculus are not leading to decisions that the public and elected officials find acceptable, possibly because of the lack of an operational means to evaluate the benefits and costs of alternative courses of action.

CONCLUSION

While the effect of policy changes or technological changes is necessarily uncertain, it nevertheless is the judgment of this Committee that in the next 5 to 10 years it is unlikely that any changes in transportation activities will be so great as to alter significantly the major identifiable sources of noise problems in transportation. Even if automobile or air travel were to be reduced in this period, for example, it is unlikely that the reduction would be so great as to make noise problems from these sources insignificant. In other words, these sources of noise are likely to remain problems in the future unless specific actions are taken either to reduce the noise or to ameliorate its adverse effects.

While these trends will perhaps be altered by changes in technology or major public policy shifts and in the location of noise-sensitive activities, those changes will not occur by themselves. They will result from conscious decisions based on consideration of the available alternatives and their benefits and costs—a subject discussed later in this report.

Finally, if there are significant changes in transportation activity or patterns, new sources of noise may emerge that may also require treatment in a manner similar to that which is suggested in this report. Since the recommendations for dealing with noise problems are general, applying to all modes and contexts, we do not feel it is necessary to attempt to speculate on possible additional sources of transportation noise.

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III BENEFITS AND COSTS OF TRANSPORTATION NOISE ABATEMENT

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6 Benefits of Noise Abatement

INTRODUCTION

In the Noise Control Act of 1972, Congress directed the Environmental Protection Agency to consider the consequences of noise for the public health and welfare. This chapter discusses the different types of health and welfare benefits that would accrue from transportation noise abatement. No attempt will be made to quantify these: some benefits are basically qualitative, the magnitudes of other effects are not known, and others have quantitative effects too indirect to permit effective quantification. The seriousness of most of the effects of noise, and, hence, the benefits from its reduction, seem clear, but the quantitative evaluation of each type of benefit must await further research.

In general, there are several kinds of effects that noise produces: direct effects on the auditory system; indirect effects on other health, social, and economic variables such as productivity; and effects on annoyance and the quality of life. It is important to note that programs that reduce the effects of noise in one domain, even if successful, may not diminish its effects in the others. For example, policies that minimize direct effects of noise, such as damage to the auditory system, may not be as successful in reducing annoyance effects.

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HEALTH BENEFITS

REDUCTION OF HEARING LOSS

One of the consequences of a reduction in transportation noise is very likely to be a reduction in the amount of hearing loss. There are several general reviews of the effects of noise upon hearing (Kryter 1970, Burns 1973, Miller 1974). They conclude that repeated or long-term exposure to noise of high intensity results in hearing loss, at first temporary, and ultimately permanent.

There is still debate in professional circles about the maximum levels of environmental noise that can be considered safe, but EPA (1974) has suggested ceilings to protect the public health and welfare. These ceilings are designed to protect the most susceptible groups in the population and incorporate a margin of safety. Table 6.1 presents a summary of these suggested ceilings.

Current transportation patterns generate noise of considerable magnitude, in some cases over 85 dB(A), enough to cause permanent hearing loss with prolonged exposure. As reported in Chapter 4, a large part of the U.S. population is exposed to the noise; EPA (1974) estimates that 16.5 million people live in urban areas of the United States where the outdoor average sound levels (primarily generated by transportation sources) are higher than those that will cause hearing loss in the long run—24 hours a day over a 40-year period. (An estimated additional 61.6 million people live in areas where the outdoor sound levels exceed those levels that interfere with outdoor activities and produce annoyance.)

When people are exposed to noise of high intensity for long periods of time, their ability to hear is impaired. One common occurrence is a temporary shift of thresholds: people are less able to detect quiet sounds after the noise exposure. The more intense the noise and the longer the exposure, the more severe the shifts are and the longer it will take for a recovery of normal hearing. The frequency of occurrence of temporary threshold shifts and the recovery time from them are predictors of hearing loss—noise-induced permanent threshhold shifts.

As EPA (1971) indicates (see Figure 4.2 above), in some urban locations ambient daytime noise levels are more than 80 dB(A) over 12-hour periods. These are well above the levels considered damaging to hearing with prolonged exposure (cf. Kryter 1970) and clearly implicate urban noise, particularly from transportation, as a causal agent in hearing loss. The degree of damage to individuals will, of course, vary with the amount of time they spend outdoors and the adequacy of the noise insulation by which they are protected. While transportation noise clearly

TABLE 6.1 Summary of Noise Levels Identified as Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety

Effect	Level[1]	Area
Hearing loss[2]	$L_{eq(24)} < 70$ dB	All areas
Outdoor activity interference and annoyance	$L_{dn} < 55$ dB	Outdoors in residential areas and farms and other outdoor areas where people spend widely varying amounts of time and other places in which quiet is a basis for use.
	$L_{eq(24)} < 55$ dB	Outdoor areas where people spend limited amounts of time, such as school yards, playgrounds, etc.
Indoor activity interference and annoyance	$L_{dn} < 45$ dB	Indoor residential areas
	$L_{eq(24)} < 45$ dB	Other indoor areas with human activities such as schools, etc.

[1] $L_{eq(24)}$ represents the sound energy averaged over a 24-hour period while L_{dn} represents the L_{eq} with a 10 dB nighttime weighting.
[2] The hearing loss level identified here represents annual averages of the daily level over a period of forty years. (These are energy averages, not to be confused with arithmetic averages.)

EPA has determined that for purposes of hearing conservation alone, a level which is protective of that segment of the population at or below the 96th percentile will protect virtually the entire population. This level has been calculated to be an L_{eq} of 70 dB over a 24-hour day.

SOURCE: U.S. EPA (1974:3) See U.S. EPA (1974:29) for a more detailed description of these levels.

contributes to hearing loss, it is impossible to apportion a specific part of the observed hearing loss in the population to that source.

Students of industrial noise have established criteria for the prediction of hearing loss as the result of continuing noise, but there remain several sources of variability that make accurate assessments of the cause of hearing loss difficult to determine after the fact:

a. individual differences in susceptibility to otological damage;
b. hearing loss differentials at different frequencies; and
c. the difficulty of separating industrial noise from other sources of environmental noise in any individual's life history.

The problems are even more complicated for an analysis of the effects of transportation noise or, more generally, environmental noise. The absence of any continuing survey of hearing impairment does not permit a yearly estimate of the rate of otological damage. Even relatively complete sources, such as the recent *The Deaf Population of the United States* (Schein and Delk 1974), do not provide data that permit the separation of cases of congenital and accident-caused hearing impairment from those cases attributable to industrial or environmental causes.

There is another and more important difficulty in determining the effects of noise on hearing. Current health and welfare levels for both environmental noise (U.S. EPA 1974) and industrial noise (National Institute for Occupational Safety and Health 1972) are founded on the belief that it is the accumulation of noise stimulation that ultimately impairs hearing. A person who undergoes hearing loss at age 50, even when presbycusis (impairment of hearing due to advancing age) is factored out—no simple matter in itself—is clearly manifesting the consequences of 50 years of acoustic stimulation. While this makes it exceedingly difficult to attribute a particular hearing loss to any one episode or source, it implies that high levels of background noise, which in our urbanized society come primarily from transportation, contribute and are implicated in almost every case of general hearing loss. (A detailed discussion of these issues can be found in the volume edited by Henderson et al. 1976.)

OTHER HEALTH BENEFITS

Reduction of transportation noise may produce health benefits other than a reduction in damage to hearing: it may affect mental health and sleep disruption; it may reduce stress and cardiovascular involvement; and it may even contribute to fetal health.

Mental Health Effects and Sleep Disruption

Intuitively, one might suppose that the intrusion of ambient noise levels so high as to be continually irksome would, over the long run, produce deficits in personality organization and functioning. However, there is little evidence that noise "drives people crazy." Rather, a recurrent finding is that humans adapt to noise to a remarkable degree (Davis 1948; Davis et al. 1959; Glass et al. 1969, 1971; Reim et al. 1971). Most of the studies linking noise to effective functioning center about sleep disruption, yet even there, adaptation seems quite usual. In many cases, it is the shorter- rather than the longer-term exposure that is more disruptive.

The effects of noise on sleep are not well understood and no general conclusion can be drawn. Whether noise rouses a sleeper seems to be determined not just by the intensity of the noise, but by its spectral distribution, the stage of sleep during which it occurs, and individual characteristics of the sleeper. It is not known whether steady sound will rouse sleepers more often than they usually waken, nor whether such sound will prevent the onset of sleep. Bursts of sound, which may be more likely to interfere with sleep, seem to be less effective rousers of sleep-deprived people (Kryter 1970).

Of the different stages of sleep, one, named REM sleep for its accompanying rapid eye movements, is thought to be important for normal functioning; it occurs about two hours a night or 25 percent of the total sleep time. Once deprived of REM sleep, there appears to be a compensatory mechanism inducing people to spend a greater amount of time in this state at another period (Kales 1969). Even if transportation noise were not an important factor in overall sleep disruption, REM disruption effects, if they could be established, might well be of special importance.

General data on sleep disruption by noise in the population are not available. Current studies (e.g., Lukas and Kryter 1970) indicate, however, that disruption is an increasing function of age—older people are more bothered than younger people. Given the gradual aging of the American population, the problem of sleep disruption will affect an increasing number and proportion of the population even if there is no increase in ambient noise levels. In other words, a reduction in transportation noise would be necessary to keep sleep disruption to its current level and, in the future, a given reduction in noise may facilitate the sleep of an increasing number of people.

Stress and Cardiovascular Involvement

In addition to its more general consequences for human health, noise has effects upon the human cardiovascular system. Some of these appear to be mechanical, others biochemical. Some investigators (Hattis et al. 1976) have described several possible mechanisms through which noise can affect the cardiovascular system. The general thesis is based on the standard stress reaction model and general adaptation syndrome as formulated by Selye (1956). This model asserts that all stressors produce nonspecific as well as specific effects and that the nonspecific stress effect is the same for all stressors and is cumulative. This suggests that even in cases where noise is not sufficiently extreme to cause cardiovascular problems by itself, it may add sufficiently to other nonspecific stressors affecting an individual to produce such effects.

Empirical evidence about the relationships of noise to cardiovascular disease is scanty. The best available studies, those by Jansen (1959, 1969), were conducted in an industrial setting and indicate that even when control differences are taken into account, workers in noisy industries have a significantly higher rate of cardiovascular disease than those in quiet industries. However, any broad generalization of these conclusions is unwarranted. A report of the NRC Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) concluded:

> So-called stress reactions in the human organism when continued for sufficiently long periods can be physiologically harmful. However, it appears that the psychological and physiological responses to noise (excluding changes in hearing) are transitory, that they adapt out with continued exposure to the noise, and therefore do not constitute harmful physiological stress (NRC 1971).

Pediatric and Fetus Effects

Although there is speculation about the effects of noise both during and immediately after pregnancy, there is a dearth of information on the effects of noise by itself or in combination with other stressors. A CHABA working group on the effects of long-term exposure to noise on human health has identified this specific gap in information and is likely to recommend to the National Institute of Occupational Safety and Health that research on this topic be given high priority.[1]

The most relevant of the available studies is an epidemiological survey by Ando and Hattori (1973) that examines retrospectively the records of women who carried to term. They studied records of over a thousand births in Japan, comparing those of mothers who resided under noisy airport flight paths with those who resided in quieter neighborhoods. Their results must be regarded as suggestive because a lack of information about procedures and measures makes it impossible to evaluate the report fully. They find, however, that even with demographic variables controlled, mothers experienced ill effects in noisy areas (with effects starting at levels of 75 dB) at twice the rate of those in quiet areas. In addition, the entire distribution of birth weights was somewhat lower for the noisy areas: for example, a 50 percent increase in the proportion of infants under 2500 grams at birth in the noisy areas. It is difficult to project the results of this one study to produce a cross-cultural prediction for the United States, but, if correct, it has implications for fetal and neonatal care.

The number of infants with low birth weight is an extremely serious matter. In the United States, which uses the same criterion of low birth weight (less than 2500 grams), there are more than 250,000 such infants born each year. This figure includes both premature infants and those carried the full 37-week term. Of these infants, 45 percent die in the first month of life. As a group they account for between 60 and 75 percent of all first-year infant deaths in the United States. Those that do survive show residual effects of their neonatal susceptibility to hypoglycemia, acidosis, renal compensation, hyperbilirubinemia, response to infection and many other diseases (National Institute of Child Health and Human Development 1972, 1975). In later life, children whose birth weight was low are still subject to a higher mortality risk and are more likely to have physical defects or to be mentally retarded. It is clear that there would be significant benefits from even a marginal reduction in the incidence of low birth weight babies that might result from decreased noise.

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[1] National Research Council (In preparation) CHABA ad hoc work group on the Effects of Long-Term Exposure to Noise Upon Human Health. Report of the Committee on Hearing, Bioacoustics and Biomechanics. Washington, D.C.: National Academy of Sciences.

WELFARE BENEFITS

ECONOMIC BENEFITS

Direct Productivity Increases

Abatement of industrial rather than environmental noise may produce measurable savings through increases in productivity. There may also be benefits from reduced transportation noise due to increased efficiency of output.

Noise interferes with job performance in a number of ways: when noise may mask a significant signal, when speed communication is required, when a worker is overloaded with more than one task at a time, and during vigilance tasks. If outside traffic noise were reduced, a secretary in an office building next to a noisy street may be better at proofreading for infrequent errors, may take dictation more accurately and may more easily be able to act simultaneously as bookkeeper and receptionist (Broadbent 1957, 1958; Glass and Singer 1972). There is some countervailing evidence. There are indications that for simple, repetitive tasks, some increase in noise level may serve as a general activator and increase rather than decrease productivity (cf. Broadbent 1958 for examples). Since this latter type of task is somewhat more specialized, it is probable that, on balance, noise reduction would increase productivity.

Noise affects productivity not so much through direct reductions in output as through higher error rates, greater variability of performance, and an increased tendency of people to make quick decisions in ambiguous situations. These effects are documented and summarized by Broadbent.[2] Further, these effects may occur without those affected by or annoyed by the noise being aware of the consequences[3] (Singer 1976).

Some of the difficulties in trying to determine and to document productivity effects of noise in any particular situation stem from the probably small magnitudes of these effects. The evidence (Broadbent 1958, Kryter 1970, Miller 1974) is equivocal. But because of the relatively small samples used in most laboratory studies and given the magnitude of the probable errors, these experiments are not sufficiently powerful to detect differences of the order of 1 or 2 percent between samples. Field studies of industrial productivity have not been able to untangle the specific effects of noise from other productivity factors, especially when the noise effects are small.

However, even a productivity loss of 1 percent for workers affected by noise—which is a value congruent with the effects reported in laboratory and field studies cited above—can represent a sizable benefit from noise reduction. However, the productivity increase resulting from the abatement of transportation noise can only result in increased productivity by those workers in industrial settings that are already quiet. Workers in a metal manufacturing plant where the ambient noise levels are 85 dB would not benefit from a reduction in adjacent freeway noise to 70 dB, but the productivity of workers in urban office buildings or quiet industries located near airport flight paths may be increased by a reduced transportation noise.

Indirect Productivity Increases

Noise may affect productivity not only directly through interference with activities, but also indirectly by influencing motivation and morale and increasing absenteeism, personnel turnover, and retraining expenses. Simply put, people may work better in a quieter workplace even though the noise itself does not interfere directly with their work. This may occur even when noise increases direct productivity—which may be the case for simple, repetitive tasks. There is some evidence that the alienating effects of this type of work are dissipated if the workers can form a friendly, communicative social group (Schachter et al. 1961, Latane and Arrowood 1963), which would be more likely to occur with less noise. Noise reduction may also be able to increase productivity indirectly by minimizing speech interference and permitting easier work and social communication on the job. This point was made indirectly (e.g., Hattis et al. 1976) in testimony at 1975 Hearings of the Occupational Safety and Health Administration of the Department of Labor on a proposed reduction in the level of maximum permissible industrial noise and was stated directly in comments on the hearings (e.g., Woodcock 1975).

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[2] Broadbent, D.E. (In press) Human performance and noise. Chapter 17, Handbook of Noise Control, edited by C.M. Harris, 2d ed. New York: McGraw-Hill.

[3] See note 2 above.

Even if the benefits of indirect productivity increases from the abatement of noise are slight, the number of workers involved may be so large that the aggregate potential savings would be considerable. As in the case of direct productivity increases, these benefits would accrue only for those workers whose workplace was relatively free of industrial noise but affected by transportation noise from outside.

OTHER BENEFITS

Resource Savings

Resource savings occur when money that would have been spent for noise abatement is saved because noise levels have been reduced by alternative means. If noise is reduced at the source, receivers do not have to insulate; if receivers insulate, sources do not have to reduce noise emissions; if path barriers are erected, neither sources nor receivers must expend resources. Since there are a number of alternative ways to reduce noise, each with its associated costs, the choice among them is in part a decision about who should bear the cost. Both pragmatic and historical reasons suggest that the costs of control will more likely fall upon sources of noise than upon receivers. If, as seems likely, the cost of source control is less than that of the receiver insulation, there will be a net savings.

The issues related to resource savings also apply to savings in construction costs. Concern for shielding the interiors of buildings from exterior noise is negligible in the operational designs of buildings and in current construction practices. Surprisingly, even structures such as hospitals, for which one might expect noise abatement to be a significant consideration, do not spend much money on it. A spokesman for the Veterans Administration hospital construction section estimates that only about 0.01 percent of the total building cost is spent explicitly for noise treatment. This amounts to $6,000 out of the roughly $60,000,000 that is spent to construct a 500-bed hospital. In contrast, a study of the soundproofing of houses in Los Angeles (Wyle Laboratories Research staff 1970) reports that, for homes with a median value of $35,000, an average of $4820 was required for a 25-dB reduction in noise. (The costs of residential noise insulation are discussed in Chapter 8.) It should be noted that if ambient noise levels were reduced not only by the quieting of transportation but by the imposition of noise standards for stationary sources, large nonresidential buildings might be forced to incur additional expenses to quiet their noise-producing heating, air conditioning, and ventilating systems.

Systems Benefits

There are two kinds of systems benefits: those that result from a noise abatement procedure and those that reduce noise as a consequence of some other procedure, such as energy saving. Some noise abatement procedures, though costly in themselves, produce offsetting savings. For example, truck noise can be reduced by using cooling fan clutches that go on only when engine temperatures reach a certain threshold. At high speeds, when fans are least necessary, the fans are off, thus eliminating a substantial amount of truck noise. While the installation of the fan clutches is costly, there is an associated saving in fuel when the fan is turned off. Such savings are referred to as systems benefits because they are an integral part of the abatement process, arising with almost every means of noise control. They include energy savings by vehicles traveling at moderate rather than at high speeds, lowered expenses for heating and air conditioning in better-insulated buildings, and reduced payments in compensation awards for impaired hearing. It should be noted that many systems benefits are unplanned or occur indirectly and that one can rarely calculate directly the savings benefits of them.

Animal and Plant Production Increases

It has been conjectured that noise may have effects not only on human beings but also on vegetative growth and on animal welfare. Some of these effects, such as those on the well-being of wildlife or domestic pets, are probably incalculable. Others, such as the increase in crop yield or profit from husbandry resulting from noise reduction, are probably, in principle, assessable in monetary amounts.

There has been very little research on the effects of noise on plants, and research on the effect of noise on animal production is inconclusive. In the Memphis State University's review paper on animals (1971), the only effects even partially documented are those whose importance is difficult to assess: for example, under noisy conditions hens tend to shift from brooders to layers. Such an effect may be beneficial for egg producers and detrimental for chicken producers, but the net consequences to society are not obvious.

DIRECT BEHAVIORAL AND PSYCHOLOGICAL EFFECTS

Children's Cognition, Learning, and Language

As Mills' recent review (1975) of the effects of noise on children has clearly argued, children are more likely to suffer from the effects of noise than adults. One of the primary effects of high ambient noise levels is a temporary disruption of speech and hearing. For adults, this means the interruption of organized communication. For children, it means more. Their speech is less redundant and its meaning is more likely to be lost. More important, noise also disrupts the learning of language and the acquisition of the ability to communicate. However, research in this area is sparse. There are few results that show a relationship between high ambient noise levels and reduction in language comprehension: Mills (1975) reports the results of these studies and their shortcomings.

There are two studies that show the relationship of transportation noise to the impairment of reading ability. Cohen et al. (1973) present evidence that the noisier the home background of the child, at least at high levels of noise, the less likely the child is to discriminate phonemes. This inability to discriminate was related to reading level in the school, and children from noisier homes performed more poorly on standardized reading tests. Bronzaft and McCarthy (1975) studied a school situated next to an elevated railroad. Students whose classrooms were adjacent to the train tracks did significantly worse in reading than similar students whose classrooms were on the other, quiet, side of the building. Since the effects reported by Cohen et al. (1973) were ascribed to noisy homes and those of Bronzaft and McCarthy (1975) were attributed to a noisy school, the locations of both schools and homes are relevant.

Annoyance and Complaints

A number of studies have investigated the characteristics of noise sources, the personalities of people who are annoyed or who complain, and the mediating factors that influence which individuals are annoyed and complain. Some of these studies have focused on aircraft noise adjacent to airports, others on highway and automotive noise.

Overall, it is clear that higher noise levels produce somewhat more annoyance and more complaints. The relationship between noise intensity and annoyance, is, however, filtered by the social context in which the noise occurs. It is not just the physical intensity of the noise that will produce complaints (at least at levels generated by the common transportation sources); people's interpretation of the source, reasons, and interfering qualities of the noise also affects the extent of annoyance or the frequency of complaints.

Cederlof et al. (1967) investigated annoyance as a function of the source of noise and found that even when various vehicles were equally noisy, automobiles were not considered as offensive as trucks or buses. Another study by Galloway and Jones (1973) found a similar dependence on source: for example, they found that at equal noise levels sports car noise is more offensive than sedan noise.

Mills and Robinson (1961), working with aircraft noise, investigated what type of interference was most unpleasant. They found speech interference most disturbing, interference with sleep and rest second. (The third factor producing annoyance from aircraft noise was fear of crashes. This is interesting because it is not the sound that is bothersome but its signal value.) These findings are consistent with others in studies by TRACOR (1971) and Galloway and Jones (1973) that conclude that noise is most intrusive when it occurs in the evening and at the recipient's home. Cederlof et al. (1967) reported that their respondents' annoyance was a function of their beliefs about the considerateness of the sources. Those who felt that pilots could avoid the noise but were inconsiderately producing it were more annoyed.

In the TRACOR study (1971), people who complained about noise in any of a variety of ways were surveyed. No particular personality pattern was predisposed to complain about noise. Those who complained were usually among the more affluent, better-educated members of their community. Data from surveys suggest that those who complain are not particularly hypersensitive to noise: that is, they are not bothered more than residents who do not complain. Kryter (1970) reports that complaints about noise from given sources diminish over time. It is unclear whether this represents adaptation to the noise on the part of the recipients or resignation to the belief that their complaints will produce no action leading to abatement. Even if the effect reported by Kryter is interpreted as adaptation, it applies to the direct effects and not to any indirect effects that may occur (see Glass and Singer 1972 and below).

The TRACOR study (1971) attempted to establish a general model for prediction of noise complaints. The authors wanted to be able to predict the effects of different variables on annoyance (without respect to particular activities disrupted). Their multiple classification analysis resulted in the following list in order of importance in predicting annoyance: fear of crashes in the neighborhood; susceptibility to noise; distance from the airport; noise adaptability; city of residence; belief in misfeasance on the part of those able to do something about the noise; and the importance attributed to the airport and air transportation, generally. Each of these variables in some form or another seems to affect annoyance from noise. When these variables are combined with a measure of noise intensity, CNR (Community Noise Rating, see Chapter 3), the prediction of annoyance was quite good: multiple $R^2 = 0.63$. This means that some 63 percent of the variation in annoyance may be accounted for by these seven essentially "social" variables and CNR.

Different models that incorporate the same types of variables have also been proposed. One has been constructed by the National Swedish Institute for Building Research (1968), using a correlational framework, and another, using a multiple regression-path analysis, has been suggested by Leonard and Borsky (1973).

All these studies are beset by one major confounding effect. Those who live in particularly noisy circumstances are most likely to have less education and lower income and to include proportionally more nonwhites than the general population. They also tend to complain less—and there is no evidence that their lower level of complaints reflect less sensitivity to the noise. In one form or another, the primary explanation offered for the relatively low volume of complaints from those most severely bothered by noise relates to social control. Those who are more educated and more affluent, it is argued, are more likely to feel that they have the power to control or at least to influence their own destinies. Thus, even though less severely affected by noise, they are more likely to take action when disturbed because they are more likely to believe that such actions will have some effect. To the extent that the system producing noise is at all responsive to their complaints, this will be a self-fulfilling belief. And the noise affecting them is as likely to be diverted to the non-complaining, lower socioeconomic status groups as it is to be abated.

Subjective Well-Being

In addition to specific annoyance or complaints, ambient environmental noise produces a reduction in what has been termed subjective well-being, an aspect of what is called the quality of life. Besides disturbing specific activities, noise also has aesthetic costs. The arguments against allowing motorcycles or snowmobiles in wilderness areas are based as much on aesthetic damage to the environment as on physical damage.

Effects of abatement on the quality of life are implicitly incorporated in some of the benefits already discussed. For example, one of the consequences of damage to the auditory system is a reduced sense of communication with other people. It is not only speech that becomes more difficult; use of the communications media such as radio, television, or telephone become progressively more difficult. Music becomes less audible, and even participation in other activities such as sports and games, to the extent that they involve speech and vocal communication, becomes harder.

One step removed from the diminished quality of life for those with impaired hearing is the diminished quality of life of those with normal hearing. Ambient environmental noise may move people indoors and away from outdoor recreational activities, it may contribute to unwillingness to use central cities, and it may bring about a noise escalation of its own. In order to talk above higher noise levels, people must speak louder. This in turn forces other sounds to grow louder, further increasing background sound level and so escalating the cycle.

Despite the apparent agreement that subjective well-being is adversely affected by sounds less intense than those which cause auditory damage, methods for the measurement of these changes are not fully developed and, consequently, the data collected are less than compelling. The main approaches that have been used to study this problem have either tried to use objective indicators of quality of life or have sought to assess subjective well-being directly.

The report of the National Planning Association (Terleckyj 1975) uses quantitative objective measures to assess quality of life (with reference to noise). Among these are some economic indicators, such as the income at the 20th percentile as a percent of the income at the 90th percentile. It also uses social indicators, such as the number of hours per person per year of discretionary time. At least in theory, it is possible to construct similar noise-effect indices, such as the cumulative noise level at the 20th percentile as a percent of the 90th percentile or the average number of days per person per year above a particular L_{eq}. However, even if objective indices of quality of life can be defined, their subjective interpretation still remains a problem. In other words, objective indicators are not an equivalent substitute for an individual's satisfaction. Thus, it is possible for people living in a central city to experience a rise in real income, an increase in the average education of their family, to receive any number of other social benefits, and yet feel less satisfied than they did a decade earlier.

A second class of studies uses interviews of a sample of the population to try to obtain a direct measure of subjective well-being. The surveys attempt to assess directly how happy people are, how well they are adjusted to their environment, or how much stress they are experiencing. Examples of this approach are the studies by Bradburn and Noll (1969) and those by Campbell et al. (1976). Campbell et al. use three dependent measures: an overall happiness rating, a stress rating, and what they call domain satisfactions. These reflect an individual's satisfaction with his or her current status in a given number of specified areas or domains. Although these procedures are well suited for overall measurement of subjective well-being, the work is global in outlook. They embrace areas so broad that noise never enters explicitly. The Bradburn studies (1969) consist of interviews studying psychiatric adjustment, and as noted above, few if any direct links have been found between noise and lack of adjustment.

If none of the available studies permits a useful evaluation of the effects of noise upon subjective well-being, what sort of study would? The study by Campbell et al. (1976), the most complete attack on the subject that is available, provides a model for what should be done. Presumably if their domain satisfaction concept were broadened and particularly appropriate samples were chosen, i.e., groups affected by noise as well as appropriate control groups, then multiple-regression techniques might be able to shed some light on this subject.

While further development of the survey techniques would contribute to our ability to evaluate subjective well-being directly, such improvements are necessary but not sufficient conditions. Even if these techniques were perfected, two other issues would remain. First, there is the distinction between prevalence and incidence: the incidence of a characteristic is measured by the percentage of the current population that will exhibit that characteristic at some time in their lives; the prevalence is measured by the percentage of the population that displays it now. Suppose, for example, that during their lifetime 50 percent of the population will suffer from a severe toothache, but that at any given time less than 1 percent will be afflicted. It is unlikely that a global assessment of life quality would pick up enough toothache sufferers to investigate the relationship between toothache and subjective well-being. On the other hand, a study of a sample of people visiting dentists' offices would enable an investigator to evaluate the disruptiveness of toothaches, but would be likely to overstate the role of toothache in American society. The parallel with noise is obvious.

A second issue relates to level of aspiration. Quality of life and subjective well-being are probably not measurable on an absolute scale, but rather are assessed by individuals in terms of their own expectations and standards. A rising level of aspiration may make an unchanging or even a more slowly improving quality of life seem to be deterioration; comparison with the fortunes of others may alter people's assessment of their own well-being. Consequently, in an evaluation of shifts in quality of life or in annoyance over time, measurements of any shifts in aspirations and expectations may also be necessary. Campbell et al. (1976) present a more complete discussion of this point.

These issues suggest that there is no readily available method, nor is one likely to be designed soon, that would relate subjective well-being or quality of life to changes in noise levels in the environment. Improved quality of life, defined as an amalgam of enhanced subjective well-being and reduced annoyance and complaints, seems to be one component of the benefits to be derived from noise abatement. It is not easy to study and does not lend itself to ready quantification or to expression in pecuniary terms. Yet as has been pointed out effectively by the National Research Council report (1975) on *Decision Making for Regulating Chemicals in the Environment*, any benefit-cost analysis must deal with these issues implicitly or explicitly if it is to avoid errors that may be substantial and critical in their significance for public policy.

INDIRECT BEHAVIORAL AND PSYCHOLOGICAL EFFECTS

In addition to its direct effects upon health and behavior, noise may also produce indirect effects—effects that may not be perceived by those undergoing them or for which noise is not considered the cause. The indirect effects can be classified as aftereffects, social effects, and learning effects.

Aftereffects

People who work or perform a task under noisy conditions and do not suffer direct impairment from it may nevertheless experience some loss in their ability to do things after the noise has ceased relative to those who have performed these tasks in quiet conditions. In about two dozen experiments (Glass and Singer 1972), people of varying ages soon adapted to the noise in the first part of an experiment. They performed the tests under noisy conditions as well as did people in no-noise control groups. Yet when performing in a second part of the experiment, after the intrusive noise had been eliminated, those previously exposed to noise did worse than those not exposed. They found fewer errors in proofreading, they did not persist as long in working on difficult or important problems, and they were not able to process conflicting information as well. These findings have direct relevance for the relationship between environmental noise and productivity, for they imply that workers who inhabit noisy homes will show aftereffects at work, irrespective of their adaptation to noise at home or to the noisiness of the workplace.

Social Effects

Another class of indirect effects are those relating to social behavior. Although noise may not interrupt task performance, it may have consequences for various kinds of voluntary behavior. For example, two laboratory studies had subjects administer electric shocks to someone presumably engaged in a learning task (Geen and O'Neal 1969, Geen and Powers 1971). They administered, at their discretion, a number of shocks and had a choice of shock intensity. Those who administered the shocks under noisy conditions gave a greater intensity of shock than those who administered them under quieter conditions.

In a coordinated laboratory and field study (Mathews and Canon 1975), the effects of noise on altruism or voluntary helping behavior were studied. In the laboratory situation, an experimental confederate dropped an arm-load of books. The subject was less likely to help pick them up when ambient noise levels were relatively high than when they were relatively low. In a field replication, the confederate dropped an arm-load of books when walking past a lawn mower. Subjects were considerably more likely to pick up the books when the lawn mower was turned off than when it was operating at a level of 84 dB(A). These effects are but two of a class of normative rules likely to be disrupted by noise: types of behavior influenced by modeling and imitation. One occurrence of noise-influenced aggression may set the model of behavior for many others and one instance in which helpfulness or altruism was inhibited may serve as a standard for future acts. Thus, a small number of direct events may affect large numbers of people.

Learning Effects

Whether noise affects learning directly is arguable, but noise is implicated in incidental learning. People often have tasks that require them to learn or process information about their environment. These can range from the learning of people's names at a cocktail party to specific employment-related materials. Though noise is unlikely to affect the direct learning, it will reduce the peripheral information processed. Thus, in a laboratory study, when subjects were presented with slides, each of which contained a four-letter word in the center surrounded by three-letter words, differences in noise level produced no differences in their ability to learn the list of four-letter words. Those who learned under noisy conditions, however, learned only the four-letter words; the control subjects learned the three-letter ones as well (O'Malley and Poplawsky 1971). Noise appears to produce concentration upon the primary learning task at the expense of the secondary, and in this case implicit, task. Since it is likely that much of our everyday knowledge and information is acquired not directly but indirectly, high ambient noise levels may require increases in effort for people to reach given levels of knowledge and information.

It should also be noted that part of the failure of many investigators to find general learning and performance effects of noise may be attributable to their use of global or general measures. A finer-grained analysis might reveal systematic noise effects. Thus in a study in which people were required to proofread under noisy conditions (Weinstein 1974), their general accuracy scores did not change. However, their ability to detect spelling and mechanical errors increased while their ability to recognize faulty grammar decreased. The net effect of noise was to focus attention more effectively and carefully on less demanding problems and to leave overall performance unchanged.

Most of the effects of noise on learning or task performance can be subsumed under the general model put forth by Broadbent (1958, 1971).[4] Humans have a limit on their capacity to process information; noise lowers this limit. If a task is well within this limit after a short adaptation period, noise will have no direct effect. But if a task comes close to the limit of an individual's information processing capacity, the addition of noise may reduce this capacity below that required by the task.

SUMMARY

This discussion of the benefits of noise abatement provides an overview of the changes that would occur and the areas in which benefits would occur. Abatement of transportation noise would result in a reduction of hearing loss, a reduction of non-auditory health effects, a decrease in speech interference, and, maybe, a decrease in sleep disruption. Noise abatement would also have a beneficial effect on worker productivity through a variety of mechanisms, it would increase learning by children living or studying in settings with high levels of noise, and, to some extent, lessen disruptive social effects. The reduction of noise can also be expected to reduce people's annoyance and increase their subjective well-being. In short, it would improve physical and psychic well-being and probably lead to an improvement in social relations: in a variety of ways, it would contribute to the quality of life.

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[4] See note 2 above.

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7 Monetary Measures of the Benefits of Abatement: Property-Value Analysis

INTRODUCTION

This chapter outlines the method most widely used to provide a monetary evaluation of the benefits of non-industrial noise abatement. The method is indirect, using as its basis observed differences in property values in quiet and noisy neighborhoods (correcting for the effects of other pertinent variables). It is necessary to use an indirect method because, as indicated in the preceding chapter, the direct measures of the benefits of noise abatement that are now available are largely qualitative. Of those that are quantifiable, only some can be expressed directly in monetary terms. Since a comparison of the benefits and the costs of any abatement program requires both variables to be measured in the same units, qualitative measures of benefits will not suffice for a cost-benefit analysis. Therefore, analytic economic methods are used to construct a proxy, or surrogate, measure of the benefits, which is calculated in monetary terms and so is directly comparable with the cost estimates. This surrogate measure is based on analyses of residential property values.

It should be emphasized that the purpose of the property-value method is not to measure financial losses to property owners. Indeed, economists do not even consider such losses in property values in themselves to constitute a net loss—the financial loss to the seller is, after all, exactly matched by the financial gain to the buyer. Rather, the property value approach is intended to estimate what monetary value the residents of noisy areas place on the physical, psychic, and social damage that they suffer.

The logic of the approach is straightforward. People who are offered a house in which they may suffer hearing loss or speech interference or other forms of damage from noise will be prepared to pay less for that house than they will be prepared to pay for a quiet residence. Moreover, the greater the noise damage they expect, the larger will be the resulting discount in the amount they will offer. In fact, in an ideal market arrangement, the size of the differential between the price of noisy and quiet houses must be an exact measure of the valuation of noise damage by buyers and sellers. For if the differential were less than this—that is, if it were insufficient to compensate buyers for the noise damage—there would be a flow of demand from noisy to quiet houses, forcing the differential to increase, and the reverse would be true if the differential in price more than made up for the damage caused by noisy houses.

In principle, then, the property-value method offers the prospect of a monetary measure of the value of noise abatement to those who would benefit from it. In practice, however, as will be emphasized later, the market mechanism is far from perfect, and this and other considerations require us to take the resulting estimates of the physical, psychic, and social benefits of noise abatement with a considerable grain of salt. But, at least for the moment, no better method has been designed to give an overall quantitative measure of the monetary benefits of noise abatement.[1]

The monetary estimates presented in this chapter are, perhaps, of some value in themselves as a representative product of the current state-of-the-art. But their primary purpose is to illustrate the issues raised by this widely used method of benefit assessment rather than to provide yet another set of figures as fuel to the controversy over the relative merits of the available estimates.

[1] There has been considerable debate in the economics literature concerning the usefulness of the property-value model for inferring the benefits of pollution abatement, particularly of air pollution. (For a discussion of these studies, see NRC 1974 and Rubinfeld, D. [In press] Market approaches to the benefits of air pollution abatement. Chapter 6, Approaches to Controlling Air Pollution, edited by Ann F. Friedlaender. Cambridge, Mass.: M.I.T. Press.). There are reasons to believe that this approach works better with regard to estimating the effects of noise than with regard to other air pollutants because noise can be perceived by the potential home buyer while many air pollutants cannot and because the level of noise at a particular location can be estimated more accurately than the level of air pollution. However, other criticisms of the approach remain, one of which is the difficulty in obtaining accurate measures of real estate values. Many of the more technical criticisms are not discussed in this report.

The first section of this chapter discusses some of the analytical approaches used to evaluate the benefits of noise abatement. The second section describes a model of the noise problem that is applicable to a wide variety of transportation modes and indicates the implications of this model for the evaluation of benefits. The third section reviews some of the evidence on the influence of airports and highways on property values. The fourth section evaluates the benefits of reducing airplane, automobile, and truck noise. These sections focus on the benefits to those who are affected by noise and who are not themselves users of the transportation system. The fifth section uses another approach to the evaluation of benefits: a cost-effectiveness analysis to find efficient combinations of interdependent noise abatement programs for given levels of expenditures. This section then examines the values that decision makers must place on noise abatement if those programs are to be justified on benefit-cost grounds.

Finally, the last section of the chapter discusses some of the limitations of the property value method of benefit measurement and seeks to suggest the likely magnitude of some of the resulting errors.

ANALYTICAL PRINCIPLES

It is important to recognize that transportation noise is a by-product of a service that has economic value. The amount of this undesirable by-product is related to the levels and distribution of transportation activities and to the quantities of resources that are allocated to the reduction of the noise by-product.

An indicator of the benefits of reducing noise is the amount people are willing to pay to be relieved from its effects. Unfortunately for both analysts and policy makers, quiet, or the freedom from noise, cannot be bought and sold by the decibel in the open market. If any site could be exposed to transportation noise only after the noise maker had purchased from the property owner an authorization to do so, it might be possible to measure directly the value that people in our society place on a reduction in their noise exposure. Such a market does not yet exist, although there are some legal means by which third parties may be compensated, e.g., in the purchase of noise easements by airport authorities. The absence of a market that places a direct value on reduced noise leads economists to use an indirect method to estimate this value. The indirect procedures usually involve the search for some market in which noise exposures are bought and sold implicitly as a tie-in with some other good. The most common variant of this implicit market approach is the use of property values to find the change in market price associated with various noise exposures.

For noise emanating from a well-defined source, the property-value approach provides a reasonable approximation of the cost of noise. Since noise decays at a smooth rate from its source, there are a variety of noise intensities available from which an individual may choose a location for a home or business.

Where the noise sources are so diffuse that they essentially become part of the ambient noise level, however, the property-value approach is less reliable. Because the ambient noise level is found throughout a given area, an individual cannot choose between a location where it is present and another where it is not. A market value cannot be placed on that which is inescapable, for market values are always revealed by choices among alternatives and the associated effects on prices. In the case of ambient noise, the choices individuals make to modify the interior noise environment—for example, by soundproofing their homes—can be used to obtain a market valuation of quiet.

Ideally, an evaluation of the benefits of transportation noise abatement would begin with the joint frequency distribution of noise from all transportation sources at each location within the area to be analyzed. Information about the interrelations among noise from all sources is needed because the benefits of some marginal reduction in noise from one source are conditional on the level of noise from other sources. The benefits of an equal reduction in truck noise at two different locations will differ, perhaps substantially, if one of the two locations is exposed to jet airplane noise and the other is not. Similarly, the benefits of a program to reduce airplane noise will depend on the character of any other noise abatement programs that may be adopted simultaneously. The benefits of various noise abatement programs are not independent, and the joint noise frequency distribution is needed to measure the marginal contribution of each program and to establish priorities among programs as well.

Suppose, for example, one is choosing among three noise abatement programs, call them Programs 1, 2, and 3. Evaluated separately, Programs 1 and 2 may yield benefits exceeding their costs, while Program 3 does not. However, it is possible that adoption of Program 1 lowers the benefits of 2 while raising the benefits of 3 to such an extent that a combination of Programs 1 and 3 is preferable to any other combination. If the programs are evaluated separately, a non-optimal choice will be made.

Unfortunately, the required joint noise distributions are not available, so this report evaluates separately the benefits of airport noise abatement and highway noise abatement. However, using work that has been done on the joint noise distribution for Spokane, the evaluation of noise abatement programs from a cost-effectiveness point of view will be illustrated.

THE PROPERTY-VALUE MODEL

A site close to an airport or a highway will usually experience fairly intensive noise, but it will also benefit from proximity to transportation. Generally, proximity to transportation will raise the value of property nearby relative to property further removed. This effect is referred to as a pecuniary externality: the increase in values arising if a highway is routed through location A would have been realized just as well had it been routed through some other equally efficient location, and the rise in property values along the highway are therefore matched by decreases elsewhere. In other words, the increase in values does not correspond to any real net social gain, but is simply a transfer of rents from one location to another.

The noise emitted from an airport or highway is a technological externality: noise uses up a real resource—quiet. When noise is "dumped" on property, the productivity of that property is affected in absolute and relative terms. Property affected by noise of high intensity is less productive for virtually any use than comparable quiet property, and its productivity as a housing site may be reduced even more than its productivity as a site for commercial activity.

Quiet residential sites will be in greater demand than noisy ones, and the resulting differences in residential property values should approximate the value that individuals place on residential quiet. Noisy commercial property should also sell at a discount compared to quiet sites, assuming equal access to labor and other inputs. Commercial property will similarly be discounted if it is noisy, if all else is the same, because workers will be less productive or customers will be less attracted to the business. Theoretically, the discount will never exceed the least costly way of completely eliminating the noise.

LOCATIONAL PREMIUMS AND NOISE DISCOUNTS: AIRPORTS

If the discount on noisy property is to be taken as an estimate of the cost of noise, then the calculation must be carried out in a manner that disentangles the locational premium from the noise discount. Consider an airport with a surrounding commercial district. If the airport were absolutely quiet and did not emit pollutants or cause congested street traffic, then the value of property near the airport would exceed the value of property some distance away. Figure 7.1a illustrates the typical behavior of the proximity value and its relation to distance from the desired location (the noiseless airport). The height of the p curve is the premium on property near the airport relative to property farther removed. The premium slopes downward at a rate roughly equal to the additional cost of transportation.

Adding airport noise, there will now be a discount on property reflecting the disutility of noise. The discount will be highest at locations close to the airport (where noise is greatest) and will diminish at a rate that reflects the disutility of noise and the rate at which noise attenuates to the ambient level. The noise discount is shown by the d curve in Figure 7.1b, and can be defined as the reduction in property value associated with a unit increase in the noise level index, all other things being equal. In the empirical studies reviewed below, this discount is expressed in dollars of depreciation on property per unit increase in noise or as the percentage depreciation of an average property per unit increase in noise.

Putting the locational premium together with the noise discount yields a net p-d curve, as shown in Figure 7.1c. The noise discount alters the locational premium and transforms the curve of property values into something like a crater. The precise effect an airport will have on property values depends upon a number of factors, such as the ambient noise level and the sound reflecting barriers or other influences affecting noise attenuation, as well as the degree of commercial activity at or near the airport and the efficiency of the transportation system. These features differ from airport to airport, so the value curve will not have the same shape near every airport.

In a city of high population density with moderate to high transportation costs, such as London, one might expect a pattern such as that shown in Figure 7.2a. A city of low density with low transportation costs, such as Los Angeles, might have a pattern like that in Figure 7.2b. Because of the very high cost of transportation and the great consequent value of proximity in the "London model," the airport increases property values on balance everywhere within the region where it has any effects. In the "Los Angeles model," the airport decreases property values over a large region nearest to it, but produces small increases in the values of properties lying some distance away. Neither of these diagrams necessarily indicates the actual state of affairs in the two cities. Empirical studies of their airports do suggest that these diagrams depict matters correctly, but none of the studies carried out so far has completely disentangled the

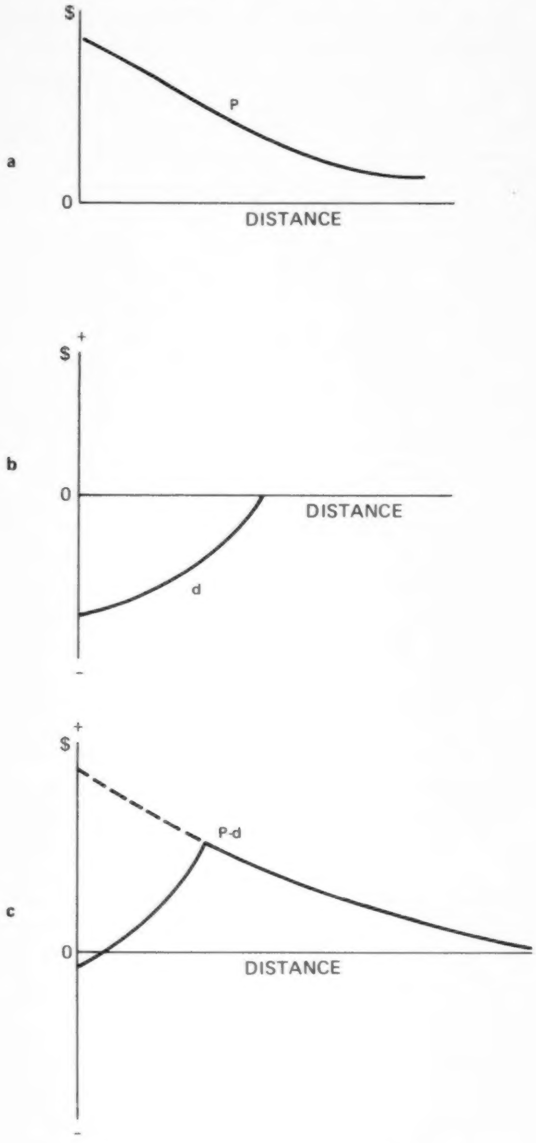


FIGURE 7.1 Property value effects of a hypothetical airport.

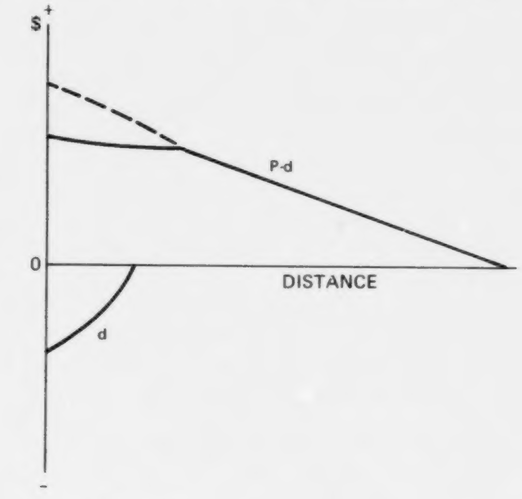
locational premium from the noise discount. Evidence relating to Love Field in Dallas yields patterns similar to the "Los Angeles model."[2]

From the point of view of evaluation of the benefits of noise reduction, it does not matter whether the effect of the airport on property values is positive or negative on balance. Since the locational premium is a pecuniary externality, it does not affect the real goods and services available to society as a whole. A net gain in property values only represents a windfall gain to those who happen to own property when the airport is announced (which, if it had been captured by the airport authority, could have helped to finance the airport's construction). The benefits of noise abatement are approximated by the "bite" taken out of the curve representing the value of proximity to the airport. This explains the paradox in the conflicting claims sometimes made by airport authorities and homeowners, with the authorities claiming the airport has increased property values, and the homeowners claiming that their property value has been reduced by the airport's noise. In this model, they can both be right. From an efficiency point of view, however, it is only the cost of the noise that is of concern, and the noise should be reduced whenever the marginal value of the reduction exceeds the marginal cost, irrespective of the overall effect of the airport on property values.

THE EFFECTS OF NOISE REDUCTION

Suppose an airport has an initial value curve such as that shown in Figure 7.2. Now, let noise be diminished with no change in the level of operations or employment at the airport. The value curve will rise near the airport and decrease at locations distant from the airport due to the increase in the supply of quiet sites relative to the supply of noisy sites. As a consequence, the premium on quiet sites is diminished. Overall, the benefits of the noise reduction include the area of property-value increase in the graph minus the area of decrease. This difference will always be positive because a saving in transportation costs must accompany the noise reduction. With their exposure to noise the same as before, individuals will now be able to live closer to the airport and thereby conserve on the cost of access to the employment, commercial activity, and transportation of the airport facilities. The cost of noise is the transportation cost that individuals must bear in order to escape it,

[2] De Vany, A. (In press) An Economic Model of Airport Noise Pollution in an Urban Environment. Carbondale, Ill.: South Illinois University Press.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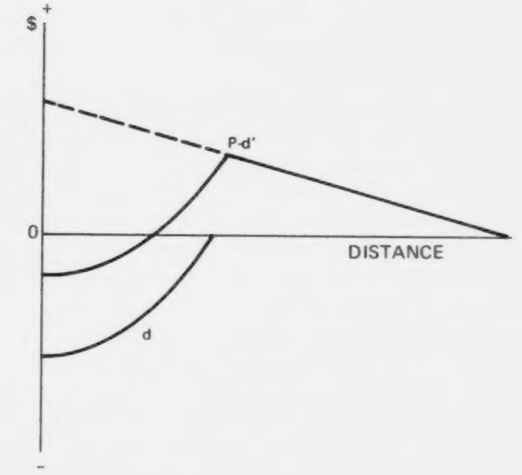
a. "London Model"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b. "Los Angeles Model"

FIGURE 7.2 Two patterns of property value effects of airports.

including both the money cost, the value of the time lost in the process, and any associated disutility.[3]

The cost of an increase in noise can be estimated by asking what additional transportation cost will be borne if individuals so exposed are relocated to new locations having noise exposure equivalent to their original site. In an orderly market, property values will reflect this transportation cost. Consequently, the cost of noise can be measured either as the differential in property values or as the increased transportation costs individuals are willing to bear to reduce their noise exposure. (Homeowners can do things other than move to alter their noise exposure; they can soundproof, air-condition and close windows, and otherwise alter their living styles.) The discount on a house with a noise exposure forecast (NEF) of 40, for example, relative to one with an NEF of 30, can never exceed the least costly means of achieving a living environment in the 40 contour that is equivalent in terms of utility to an environment in the 30 contour.

HIGHWAYS

This model applies to highways as well as airports (see Gamble et al. 1974). Access to highways has a positive value and highway traffic also emits noise and other pollutants. It is expected that a highway will transform the curve of property values in a manner similar to that of an airport. In this case, however, noise is radiated over a smaller distance and attenuates at a more rapid rate because noise from a low altitude source usually encounters a profusion of reflection agents and barriers such as vegetation, buildings, etc.; therefore, the noise discount is likely to be confined to a fairly narrow band around the highway. The locational premium will slope away at a rate representing the value of access to the highway.

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[3] This can also be expressed in terms of a moving rule for the household (Walters 1975:37). Let N be the differential noise evaluation for two properties that are identical except for noise exposure. Then

$$NS+D+R \quad \text{(move)}$$
$$NS+D+R \quad \text{(stay put)}$$

where S is the difference in consumer surplus associated with the two residences, D is the capital loss due to differences in prices, and R is search and removal (transportation) costs. The values of N, S, R, and D are the present values of expected future outlays or valuations at some particular rate of time preference.

EMPIRICAL EVIDENCE ON THE NOISE DISCOUNT

The various noise indices that have been designed to measure airplane or road traffic noise do not have as their objective an explanation of the influence of noise on property values or locational choices of individuals. There is evidence, however, that noise, as measured by the standard indices, does adversely affect property values, all other things being equal. The various noise indices do contribute to an understanding of urban property values and are, therefore, measuring a phenomenon to which individuals react in their economic behavior.

AIRPLANE NOISE

Two very able reviews of the evidence from studies through 1974 are available (Walters 1975, Nelson 1975[4]). While there are several unsettled technical issues, the available evidence suggests that airplane noise reduces property values, and the amount and quality of the evidence is reasonably impressive.

Table 7.1 summarizes the studies of airplane noise and property values through 1974. The studies cited place the percent reduction in average property value per unit NEF in the range of 0.4 to 2.0 percent.[5] The cities included in the samples of those studies are diverse in climate, population density, and mean housing values, and the functional forms employed by the authors also differ, so it is not surprising to find some differences in the estimates of property values. (Indeed, the discussion of the preceding section suggests that because of differences in the characteristics of different cities this can be expected to be the rule rather than exception.) One point to be noted in evaluating these studies is the range of NEF values considered. The Emerson study (1969) deals with a range from about 30 to 55 NEF and is the only study that includes values above 45. It therefore measures response to noise well above the range considered by the other studies; however, it does not include any data in the 20- to 30-NEF range, which is the range within which airplane noise is generally considered to become noticeable. (The ambient noise level is about 20

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[4] A slightly revised and expanded analysis of the data in the Nelson Study appears in An Analysis of Jet Aircraft Noise and Residential Property Values. Institute for Research on Human Resources. University Park, Pa.: Pennsylvania State University. (Unpublished)

[5] The 2.0 percent noise discount is from Paik's study (1972), which employs 1960 data. All other studies in Tables 7.1 and 7.2 use data from the period 1967-1971. A comparison of 1960 results with the later period suggests a decline in the noise discount over time. This may be due to an adjustment toward a new long-run equilibrium or it may reflect soundproofing or air-conditioning of homes and the introduction of new, quieter, wide-body jets. For a study of the noise discount over time, see Crowley (1973).

NEF.) In the other studies, NEF areas above 45 are not considered so that the most heavily affected areas are not included.

More recent work has been done by Nelson (1975, 1976), De Vany,[6] and Mieszkowski and Saper.[7] Their estimates are compared in Table 7.2. If the reductions in value per unit of NEF are adjusted to a mean housing value of $35,000, which is the sum reported in the Mieszkowski and Saper study,[8] then the discount becomes $350 and $204 per NEF for the Nelson and De Vany studies, putting them in fairly close agreement with the Mieszkowski and Saper discount of $210. The De Vany study[9] indicates that the overall effect of the airport on land values is positive, even though there is substantial noise damage.

HIGHWAY NOISE

The model suggests that empirical studies of the effects of highways on property values should find a narrow belt of net noise damage around each highway, surrounded by a region in which property values are increased by the accessibility afforded by the highway. Although large-scale, multivariate statistical studies for highway noise are limited in number, the available evidence from three studies is of reasonable quality and consistency. Unfortunately, each study employed a different index of traffic noise, which somewhat complicates comparison of the damage estimates.

Table 7.3 summarizes the studies that relate property values to highway noise. While the percentage of damage per unit of noise in dB(A) seems rather high for the Bogota (New Jersey) sample, the other areas exhibit a fairly narrow range of damages from 0.20 to 0.60 percent. A more exact comparison of marginal damages can be made by using the traffic noise index (TNI), which is the noise level exceeded 10 percent of the time minus the noise level exceeded 90 percent of the time (see Chapter 3). A 1-unit change in the TNI is equal to about a 1.1 unit change in the noise pollution level (NPL) index and about a 1.25-unit change in L_{eq} (Illinois Institute for Environmental Quality 1976). Converting to TNI units, marginal damages are $147, $168, and $102, respectively.

Unfortunately, none of these studies attempted to disentangle completely the locational premium from the noise discount. Using information on the value of access compiled by the Washington, D.C. Council of

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[6] See note 2 above.

[7] Mieszkowski, P. and A.M. Saper. An estimate of the effects of airport noise in property values. Journal of Urban Economics. (Forthcoming)

[8] See note 7 above.

[9] See note 2 above.

TABLE 7.1 Summary of Jet Airplane Noise Pollution Studies[1]

Study	Functional Form for Noise	Noise Coefficient	R^2	Marginal Damage Estimate[2]	Range of Noise Values	Percent Reduction in Average Property Value per Unit NEF
Emerson (1969)	Log	–0.003	0.79	–$123/NEF	100–125 CNR (30–55 NEF)	0.4
Paik (1972)	Log Semi-Log	–0.018 to –0.025	0.78	–$560/NEF	20–40 NEF	2.0
Dygert (1973)	Semi-Log	–0.005 to –0.007	0.60	–$140/NEF	25–45 NEF	0.5
Price (1974)	Linear	–1.267	0.50	–$100/NEF	25–45 NEF	0.4

[1] Data derived from Nelson (1975:8-10). See also Walters (1975:103).

[2] In 1970 dollars and relative to a $28,000 property.

TABLE 7.2 Summary of Recent Jet Airplane Noise Pollution Studies[1]

Study	Functional Form for Noise	Noise Coefficient	R^2	Marginal Damage Estimate[2]	Range of Noise Values	Percent Reduction in Average Property Value per Unit NEF
Nelson (1975 and 1976)	Semi-Log	-0.010	0.86	-$280/NEF	20–45 NEF	1.0
Mieszkowski and Saper (1975)	Linear Semi-Log	N.A.	0.90	-$210/NEF	25–35 NEF	0.60
De Vany (1976)	Log					
Distance to Airport						
Within 1 mile		-0.065	0.71	-$ 33/NEF	20–55 NEF	0.22
1 to 2 miles		-0.050	0.88	-$ 52/NEF	20–50 NEF	0.22
2 to 3 miles		-0.123	0.79	-$164/NEF	20–45 NEF	0.58

[1] Data derived from Nelson (1975:8-10). See also Walters (1975:103).

[2] In 1970–71 dollars. The average property values for the three studies are about $28,000, $35,000, and $22,000 (all areas), respectively.

TABLE 7.3 Summary of Highway Noise Pollution Studies

Study	Area	Noise Measure	Marginal Damage Estimate Per Unit Noise[1]	Percent Reduction in Average Property Value per Unit Noise
Nelson (1975)	Suburban Wash., D.C.	TNI	-\$147	0.40
Vaughan and Huckins (1975)	Chicago	L_{eq}	-\$135	0.60
Gamble et al. (1974)	North Springfield, Va.	NPL	-\$ 69	0.20
	Bogota, N.J.	NPL	-\$646	2.22
	Rosedale, Md.	NPL	-\$ 60	0.24
	Towson, Md.	NPL	-\$141	0.42
	All areas	NPL	-\$ 82	0.26

[1] In 1970-71 dollars, average property values are about \$32,000, \$22,500, and \$31,000 (all areas), respectively.

Governments, Gamble et al. (1974) were able to put together a partial picture of the effect of a highway for the North Springfield area. Using a constant noise damage value of \$69 per dB(A) per residence and a constant accessibility value of \$2,955 per residence, one obtains a value curve like that shown in Figure 7.3. At a distance of roughly 1000 feet from the highway, noise from the highway falls to the ambient level, about 55 dB(A), and there is no further loss in value. The assumption that the accessibility value is constant over distances up to 1000 feet is probably realistic, although for much greater distances one would expect the accessibility value to fall with increasing cost of access to the highway.

BENEFITS OF NOISE ABATEMENT

AIRPLANES

When the property-value model is used to evaluate the benefits of noise abatement, a series of assumptions and extrapolations must be made.[10] Jet airplanes typically serve many airports, so the benefits of making the airplanes quieter are distributed among many places, yet rigorous property value studies have been conducted for about 10 airports at most. It is necessary, therefore, to extrapolate a damage value per NEF from one study or an average of several studies. Furthermore, the available data on noise exposure are far from complete. What is available is an

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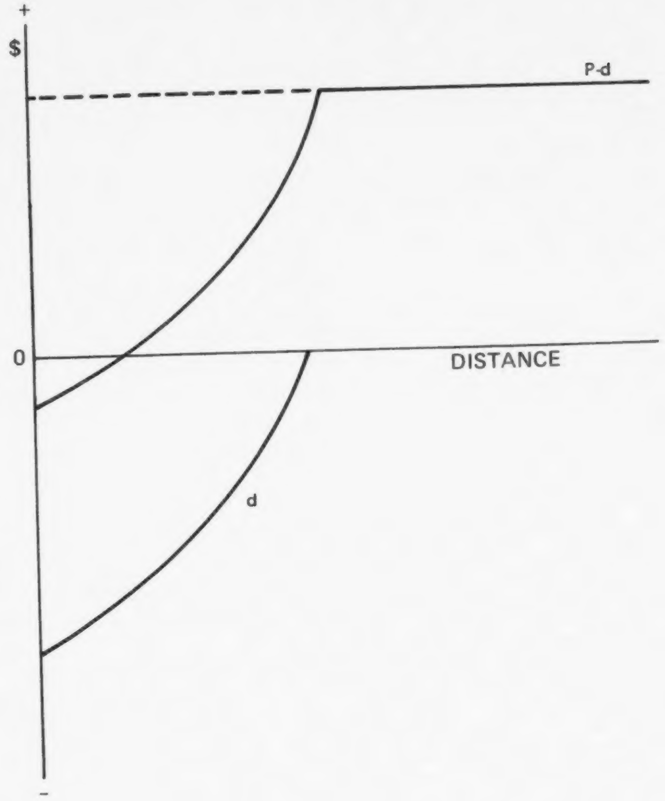
[10] For some discussion of the the technical aspects of these issues, see Freeman (1974), Oron et al. (1974), and Polinsky and Shavell (1976).



SOURCE: Modified from Gamble et al. (1974)

FIGURE 7.3 Property value effects of a highway.

estimate of the number of people who reside within the NEF-40 and NEF-30 contours (but see U.S. EPA 1974c). As a consequence, the analyst is forced to assume that those persons who live outside the 30 contour obtain essentially no benefits from noise abatement, in spite of evidence that noise causes some annoyance within the 25 contour.

This report has previously argued that it is erroneous to take a project-by-project approach when, in fact, the benefits of airplane noise

TABLE 7.4 Estimated Number of People Residing in NEF 30+ and NEF 40+ and Associated Land Area in 1972

Noise Level	Population	Acres[1]
NEF 30+	6,200,000	965,000
NEF 40+	630,000	114,000

[1] Land area includes residential, industrial, commercial, and farmlands, as well as highways and surface transportation facilities. Not all this land area is incompatible with the imposed noise levels.

SOURCE: Safeer (1975)

reduction depend on other projects that affect environmental noise. Since it is always preferable to give priority to the least costly way of achieving a given reduction in noise, it would be best to evaluate the benefits of airplane noise abatement programs only after we know how many people would be saved from exposure to NEF-30 by the adoption of, for example, all more cost-effective highway noise control programs. Similarly, it would be best to evaluate highway noise abatement programs only in terms of the benefits to those people who would remain in the NEF 30 contour after all more cost-effective aircraft noise abatement programs have been adopted. However, since the data necessary for such analyses are not available, aircraft and highway noise are considered separately in this discussion.

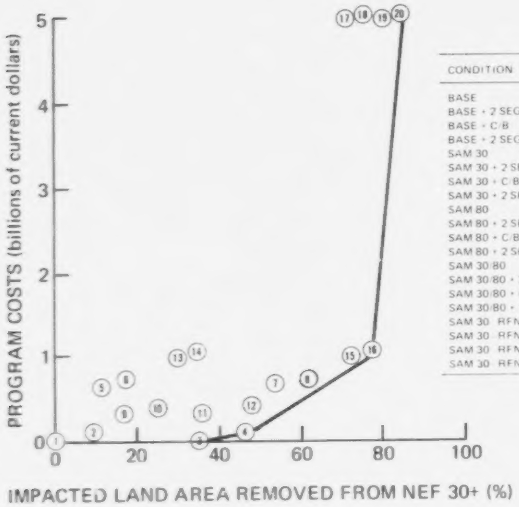
Table 7.4 provides estimates of the size of the population or land area affected by noise. The estimates of noise damage per residence from one or several of the studies reviewed above can be translated into benefits of noise reduction per residence, per person, or per acre of land, but only if there are specific alternative noise abatement programs to evaluate. For any given level of abatement, the program or combination of programs that is cost-effective—i.e., that achieves the target level of abatement at least cost to society—is to be selected. The benefits of these programs, starting with the most cost-effective program and adding incremental programs so long as marginal benefits exceed marginal costs, are then evaluated.

Safeer (1975) has provided a relative ordering of the major options for airplane noise abatement in terms of the numbers of people and land area removed from the NEF 30+ and NEF 40+ areas. Five major alternatives were analyzed:

1. retrofitting of all JT3D- or JT8D-powered aircraft with new nacelles containing sound absorption material (SAM);

2. retrofitting of all JT8D-powered aircraft with refanned engines and new nacelles (REFAN);
3. modifying approach procedures (two-segment);[11]
4. modifying takeoff procedures (thrust cutback); and
5. acquiring land within the NEF-40 contour.

The results of Safeer's analysis are shown in Figures 7.4 and 7.5. Each option number is listed to the right of the figure under a column heading indicating the date at which the program in question is assumed to be in full operation. It should be noted that some of the procedures examined, e.g., two-segment landings, are not fully applicable to all aircraft. Safeer then gives the population and land area removed from the NEF-30+ and NEF-40+ contours by the various alternatives together with the benefits associated with the programs. He employs a benefit estimate using Paik's study (1972) based on 1960 census data.



CONDITION	CODE 1978	CODE 1981
BASE	1	
BASE + 2 SEG	2	
BASE + C/B	3	
BASE + 2 SEG + C/B	4	
SAM 30	5	
SAM 30 + 2 SEG	6	
SAM 30 + C/B	7	
SAM 30 + 2 SEG + C/B	8	
SAM 80	9	
SAM 80 + 2 SEG	10	
SAM 80 + C/B	11	
SAM 80 + 2 SEG + C/B	12	
SAM 30/80	13	
SAM 30/80 + 2 SEG	14	
SAM 30/80 + C/B	15	
SAM 30/80 + 1 SEG + C/B	16	
SAM 30 RFN 80		17
SAM 30 RFN 80 + 2 SEG		18
SAM 30 RFN 80 + C/B		19
SAM 30 RFN 80 + 2 SEG + C/B		20

SOURCE: Safeer (1975)

FIGURE 7.4 Cost vs. effectiveness, NEF 30+.

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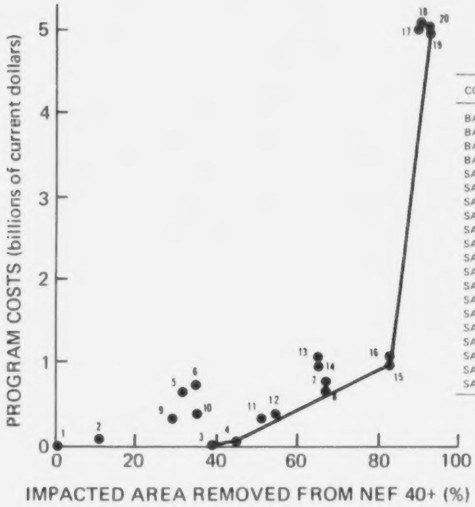
[11] The FAA has very recently decided not to prescribe a two-segment approach, primarily for reasons of safety. In its stead, the FAA will require noise abatement by means of landing flap setting procedures (Federal Aviation Administration and the U.S. Department of Transportation 1976).

Each dot in the figure shows the cost and noise reduction corresponding to the identified program or combination of programs. The aim is to select the option that is least costly, given the land area removed from the NEF-30+ or NEF-40+ contour. These cost-efficient options are given by the envelope curve that goes through the lowest dots in the diagram. For example, the curve in Figure 7.4 indicates that options 2, 3, 4, 16, and 20 are the most cost-effective means by which to remove land incrementally from the NEF-30+ contour.

Nelson's study (1975) contains a more explicit calculation of benefits based on the empirical studies of airplane noise and property values for 1967-1971 data. Four major alternative abatement strategies were examined.

1. No Change. Even with no new control programs, major reductions in noise levels will occur as the result of introduction of new, quieter jets (B747, DC-10, L-1011, and others) under the standards of the FAA's Federal Aviation Regulation Part 36 (FAR 36) and the phasing out of the airplanes now in use.

2. Two-Segment Approach. A 6°/3° two-segment landing approach



CODE

CONDITION	1978	1981
BASE	1	
BASE + 2 SEG	2	
BASE + C/B	3	
BASE + 2 SEG + C/B	4	
SAM 30	5	
SAM 30 + 2 SEG	6	
SAM 30 + C/B	7	
SAM 30 + 2 SEG + C/B	8	
SAM 80	9	
SAM 80 + 2 SEG	10	
SAM 80 + C/B	11	
SAM 80 + 2 SEG + C/B	12	
SAM 30/80	13	
SAM 30/80 + 2 SEG	14	
SAM 30/80 + C/B	15	
SAM 30/80 + 1 SEG + C/B	16	
SAM 30 RFN 80		17
SAM 30 RFN 80 + 2 SEG		18
SAM 30 RFN 80 + C/B		19
SAM 30 RFN 80 + 2 SEG + C/B		20

SOURCE: Safeer (1975)

FIGURE 7.5 Cost vs. effectiveness, NEF 40+.

for all airplanes will reduce noise levels, especially outside the NEF-40 contour. It is assumed that two-segment instrument landing systems can be installed and tested and approach procedures instituted during 1976 and 1977.

3. SAM 8D/3D. This program requires all old JT8D- and JT3D-powered airplanes to be fitted with acoustically treated nacelles beginning in 1975. It is assumed that all civilian airplanes can be fitted with quiet nacelles by the end of 1978.
4. REFAN 8D/SAM 3D. This requires all old JT8D-powered airplanes to be fitted with refanned engines beginning in 1978 and all JT3D engines to be fitted with acoustically treated nacelles beginning in 1976. It is assumed that these modifications can be completed by the end of 1981 and 1978, respectively.

Nelson evaluates alternatives 2, 3, and 4 in terms of the resulting incremental noise reduction as compared with the no change option. This comparison correctly anticipates that, within the period considered by the study (1975-1997), some of the noisier airplanes will be retired from the fleet and that new airplanes coming into the fleet will be somewhat less noisy as a result of FAR 36. Unfortunately, it is extremely difficult to anticipate the exact rate at which older airplanes will be retired. Nelson's analysis, which uses a Department of Transportation forecast, is probably overly optimistic with regard to the retirement of older airplanes. As a consequence, the benefits of abatement measures are probably undervalued.

In order to calculate aggregate benefits, it is necessary to forecast: (1) the reduction in NEF levels over time resulting from each noise abatement alternative; (2) the percentage of persons within the NEF-30+ contour who experience reduced noise levels; and (3) the dollar value of benefits per person or per residence per NEF.

Table 7.5 shows the effect of each noise abatement alternative on noise exposure through the year 1987. The information in this table indicates the reduction in NEF values from each abatement program and the percentage of persons remaining inside the NEF-30+ contour. Aggregate benefits are calculated under several alternative assumptions about what is the appropriate population: for example, whether or not those people removed from the NEF-30+ contour continually share in the benefits of a specific abatement program. In light of evidence that the most stringent abatement program would only reduce the NEF-30 contour to about NEF 25, it seems appropriate simply to use the population in 1975 inside the NEF-30+ contour or about 5.2 million people (84 percent of 6.2 million).

TABLE 7.5 Impact of Airplane Noise Abatement on Noise Exposure, 1975-1987

	Year[3]			
Abatement Program[1,2]	1975	1978	1981	1987
No Change				
Δ NEF	−2.1	−2.1	−2.5	−2.4
Efficiency	84.0%	72.0%	67.0%	70.0%
Two-Segment Landing				
Δ NEF	0.0	−0.5	−0.6	−0.6
Efficiency	84.0%	61.0%	54.0%	55.0%
SAM8D/3D				
Δ NEF	−0.4	−1.7	−1.6	−1.3
Efficiency	84.0%	56.0%	57.0%	58.0%
REFAN8D/SAM3D				
Δ NEF	0.0	−1.7	−5.3	−4.9
Efficiency	84.0%	56.0%	27.0%	31.0%

[1] The Δ NEF data were supplied by John E. Wesler, Office of Noise Abatement, U.S. Department of Transportation.

[2] The efficiency factor is the percentage of the 1972 population remaining inside NEF 30+ due to each abatement program after accounting for introduction of new airplanes. Population efficiency data are from unpublished supporting data from Bartel, Sutherland and Simpson (1974), summarized on page 3-33 of their report. These data were adjusted to account for the population efficiency of each alternative program without two-segment landing.

[3] NEF measurements depend on the number of airplane flights. Therefore, Δ NEF factors decrease and efficiency factors increase after 1978 or 1981 due to increases in air travel. The efficiency factors for two-segment landing are affected by the fact that this option would apply to all airplanes (if feasible).

SOURCE: Derived from Nelson (1976).

As his measure of benefits, Nelson uses an estimate of $140 per residence per NEF (in 1970 dollars). To evaluate this figure, note that the average property value in 1970 for metropolitan suburbs was about $21,000. Thus, a noise discount of $140 per NEF is about 0.7 percent of the average residential property value in 1970. A review of Tables 7.1 and 7.2 suggests that for studies using 1967-1971 data, the noise depreciation value is in the range of 0.4 to 1.0 percent. Although it would be preferable to obtain aggregate benefits by separate calculations for each airport, reflecting the diversity that no doubt exists, $140 per NEF is at the midpoint of the range of the damage figures available from empirical studies.

Table 7.6 shows the estimates of the discounted present value of the four abatement programs. These estimates assume a real interest rate of 8 percent, the retirement of all old jet airplanes by 1997, and a 2-3 percent growth in benefits to reflect income growth and associated increases in

TABLE 7.6 Total Discounted Benefits of Jet Airplane Noise Abatement, 1975–1997 (millions of 1974 dollars)

Abatement Program	At an 8% Interest Rate Until the Year 1997
No Change	$ 998.3
Two-Segment Landing	214.2
SAM8D/3D	426.5
REFAN8D/SAM3D	1,109.2

SOURCE: Nelson (1976).

willingness to pay for noise abatement. Estimated benefits, in 1974 dollars, range from $214 million for two-segment landings to $1,109 million for the REFAN program.

Nelson's noise discounts can be compared to the price paid for flyover easements for two airports. The average easement cost in Columbus (Ohio) was $2414 for 30 easements, and the average cost in Denver (Colorado) was $1000 for 32 easements (National Bureau of Standards 1971). If the residences on which the easements were purchased were in the NEF-45 contour, this would suggest a discount per NEF of about $112 (average easement of $1684 for a reduction from NEF 45 to NEF 30, which is not far out of line with the results of the studies cited above).

MOTOR VEHICLES

The estimation of benefits from reduction of noise from motor vehicles is far less advanced than it is for aircraft noise abatement. None of the studies examined has shown that central city urban property values are affected significantly by motor vehicle noise per se. This is partly to be expected because noise in highly urbanized areas comes from so many sources. As a result, a feasible reduction in traffic noise will usually not decrease noise exposure sufficiently to make a significant difference to the home owner. Moreover, the relative uniformity of the noise level in an urban area means that it is difficult to ascribe statistically any significant portion of the difference in property values between one neighborhood and another to differences in noise levels; usually, the location decision that most affects an individual's noise exposure is in the choice between an urban or suburban location. Consequently, only a comparison of urban and suburban property values, adjusted for accessibility, would seem to offer a way of discovering what value is placed on relief from high ambient noise levels. As an alternative, one might investigate how apartment rents vary with noise exposure or how much individuals are willing to pay to modify their interior noise level relative to the ambient level. The studies by Nelson (1975) and Vaughan and Huckins (1975) suggest that an ambient noise level of about 50 dB(A) is the approximate threshold below which a change in the noise level has no impact on property values. But it is not possible to determine from the available evidence if an increase in the ambient level from, say, 50 dB(A) to 60 dB(A) has any effect on property values, assuming that the frequency and intensity of intermittent sounds remain unchanged.

On the other hand, reasonably strong results are reported in studies of the effect of highway noise on suburban and urban residential property values, most notably in the area of freeways. In such areas, there is a well-defined source of noise, and noise exposure can be varied substantially by the choice of proximity to the freeway. In addition, EPA (1974a:6-15) has provided estimates of populations exposed to various noise levels that also take account of proximity to urban streets. These data provide a basis for an extrapolation of the benefits of highway noise abatement, although we feel these estimates are tentative at best and should be revised as more data become available. (See also Vaughan and Huckins [1975] and Illinois Institute for Environmental Quality [1976] for benefit-cost comparisons of selected abatement programs.)

Nelson's report (1975), with his later corrections, provides a basis for estimation of the benefits of abatement of noise from medium- and heavy-duty trucks in excess of 10,000 pounds gross vehicle weight rating (GVWR). Four abatement programs are considered (see U.S. EPA 1974a, 1974b).

1. Current operating rules for interstate motor carriers and new cars. The Interstate Motor Carrier Noise Emission Standards (U.S. EPA 1974b) require that all motor vehicles above 10,000 pounds GVWR operated by motor carriers engaged in interstate commerce meet the following standards as of October 1975:

   a. no more than 86 dB(A) at 50 feet in speed zones at or under 35 mph under all conditions, and

   b. no more than 90 dB(A) at 50 feet in speed zones over 35 mph under all conditions.

2. Model 1. An illustrative regulatory program under which new trucks of over 10,000 pounds GVWR will be required not to exceed the following noise levels after October of the year indicated:

a.	1976	83 dB(A)
b.	1980	80 dB(A)
c.	1982	75 dB(A)

TABLE 7.7 Reduction in Day-Night Sound Level (Ldn) in dBA Relative to 1974 Values

Abatement Program	1976	1980	1982	1990	1992
Freeways					
Operating rules and new cars	-2.4	-2.4	-2.4	-2.4	-2.4
Model 1	–	-1.2	-2.6	-6.0	-6.2
Model 2	–	-2.0	-3.8	-6.2	-6.2
Model 3	–	-1.2	-2.6	-6.0	-6.2
Urban Streets					
Operating rules and new cars	-0.7	-1.2	-1.4	-2.0	-2.0
Model 1	–	-0.3	-0.7	-2.9	-3.3
Model 2	–	-0.6	-1.1	-3.0	-3.5
Model 3	–	-0.3	-0.7	-2.9	-3.3

SOURCE: U.S. EPA (1974a:6-20).

3. Model 2. A program whose restrictions are the same as in Model 1 but whose effective dates are different:

a. 1976	83 dB(A)
b. 1977	80 dB(A)
c. 1980	75 dB(A)

4. Model 3. A program establishing separate standards for gas engine and diesel engine powered trucks with the following effective dates:

	Gas	Diesel
a. 1976	80 dB(A)	83 dB(A)
b. 1977	80 dB(A)	83 dB(A)
c. 1980	75 dB(A)	80 dB(A)
d. 1982	75 dB(A)	75 dB(A)

Table 7.7 shows the estimated reduction in the day-night sound level (L_{dn}) associated with each program. The reductions indicated are incremental so that, for example, the current operating rules together with Model 1 regulations would yield a total reduction of 3.6 dB(A) along freeways in 1980. Table 7.8 presents estimates of the population expected to be exposed to noise levels in excess of 55 L_{dn} under the four programs for the period 1974-1992.

For his estimate of benefits, Nelson used a (corrected) discount of 0.4 percent per dB(A) per residence or about $147 per dB(A) per residence. Since this value is based on property values in suburban Washington, D.C., it may somewhat overestimate the costs of noise in the United States as a whole. The total benefit calculations assume that: (1) the 1974

TABLE 7.8 Populations Exposed to Day-Night Sound Level (Ldn) Greater than 55 Under Alternative Programs (millions of people)

Abatement Program	1974	1976	1980	1982	1990	1992
Operating Rules and New Cars						
Freeways	2.7	2.1	2.1	2.1	2.1	2.1
Urban Streets	34.6	31.5	29.4	28.4	26.0	26.0
Model 1						
Freeways	2.7	2.1	1.8	1.6	1.1	1.0
Urban Streets	34.6	31.5	28.0	25.6	15.9	14.9
Model 2						
Freeways	2.7	2.1	1.7	1.4	1.0	1.0
Urban Streets	34.6	31.5	27.0	23.2	14.9	13.8
Model 3						
Freeways	2.7	2.1	1.8	1.6	1.1	1.0
Urban Streets	34.6	31.5	28.0	25.6	15.9	14.9

SOURCE: U.S. EPA (1974a:6-21).

TABLE 7.9 Total Discounted Benefits of Heavy-Medium Duty Truck Noise Abatement, 1976–2010 (billions of 1970 dollars)

Abatement Program	At a 10% Interest Rate Until the Year 2010
Operating Rules - New Cars	$2.53
Model 1	2.53
Model 2	2.99
Model 3	2.53

SOURCE: Nelson (1975:10–17 as corrected).

populations continually receive benefits from reductions in noise through the year 2010; (2) benefits increase at a rate of 5 percent per annum, which is the predicted growth rate for new truck sales; and (3) the appropriate real interest rate is 10 percent. The resulting estimates of the total discounted benefits from each of the four programs are shown in Table 7.9 in 1970 dollars. For example, Model 1 would yield discounted benefits of about $2.5 billion in 1970 dollars.

PARAMETRIC EVALUATION OF INTERDEPENDENT NOISE ABATEMENT PROGRAMS

As discussed earlier, it is incorrect to evaluate noise abatement programs independently when they are in fact interdependent; that is, when the marginal benefits of each program depend upon the magnitudes of the standards selected for other programs. Examples of these interdependencies are abundant. For instance, the benefits of truck noise abatement will differ according to the programs adopted for automobiles and airplanes if portions of the population are exposed simultaneously to each of these noise sources.

Two problems arise when interdependent programs are evaluated separately. First, the marginal benefits of an individual program may be over- or under-valued if they are estimated alone. For example, the marginal benefits of airplane noise abatement may be increased relative to those of other programs if a strong program of automobile traffic noise abatement is adopted simply because airplane noise is no longer masked effectively by urban traffic. At the same time, however, the marginal benefits of low-speed truck noise abatement would probably diminish. Consequently, the optimal combination of noise abatement strategies cannot be determined unless their interdependence is recognized.

While these interdependencies are often recognized in evaluations of programs designed to cope with noise emanating from one transportation mode (see, for example, the Safeer study [1975] discussed earlier), this important issue is generally ignored when several modes are under consideration. Thus, very little work has been done to integrate all modes of transportation in the calculation of cost-effective or cost-benefit programs for the abatement of transportation noise. As a consequence, the total benefits of noise abatement have almost certainly been miscalculated, although we do not know, in general, whether they have been overestimated or underestimated. More important, the combination of programs recommended by several independent analyses is almost certain to be inefficient. In principle, each program should be carried to the point at which its marginal benefits in noise reduction received for each dollar of expenditure is equal to that of all other programs for all transportation modes. This is necessary to ensure that the maximum noise reduction is secured for any given level of expenditure.

AN ILLUSTRATIVE STUDY

A better approach is illustrated in a pioneering study of noise in Spokane by Wyle Labs.[12] The Wyle study attempted to characterize the joint distribution of noise from all transportation sources and then defined cost-effective combinations of noise abatement programs considering all transportation modes for various given levels of expenditures. Using the results of this study, it can be seen what implicit (negative) money values one would have to attribute to noise in order to justify the funding of the cost-effective noise programs, that is, how to determine the minimum benefit levels at which such abatement programs become worth the cost of carrying them out. Whether these break-even benefit values exceed the corresponding figures derived from the property-value approach is also considered.

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[12] On March 17, 1977, Wyle and the Motor Vehicle Manufacturers Association circulated a letter stating: "both Wyle and MVMA believe that the Spokane study *is not sufficiently accurate* or definite to be used as a data reference . . . [but they do] believe that this unique approach in studying community noise and countermeasure cost-effectiveness *is* appropriate and its development as a policymaking tool should be continued."

The community of Spokane is described in the Wyle study in terms of cells of population, with the people in each cell all living within an (approximately) homogeneous noise environment. For one particular time period, a noise level figure, defined by L_{eq}, is calculated at a central point of each cell, taking into account noise from all sources and propagation losses. The effectiveness of a given noise reduction is then defined as the reduction in the percentage of people in the cell reacting adversely. This percentage of people reacting adversely is called a noise impact index (NII).

The Wyle study selected three expenditure levels—$5, $10, and $30 million—and made a set of assumptions about the measures that can be used to abate noise from each source and about the cost of these measures. It then determined the particular combination of such measures that would minimize NII. As would be expected, the relative expenditures for different measures and for different noise sources change as the total amount to be spent is varied. For example, using the Wyle data as illustrative, if $5 million is to be spent on medium-cost measures, the optimal allocation assigns 72 percent of the total to reducing automobile noise and nothing to barriers, home insulation, and relocation; with $10 million, the optimal allocation assigns 44 percent to reducing automobile noise and nothing to barriers, home insulation, and relocation; and with $30 million, the optimal allocation assigns 23 percent to reducing automobile noise and 57 percent to barriers, home insulation, and relocation.

These comparisons are based on strong assumptions. Unfortunately, the procedures, analysis, and data in the Wyle report do not permit an actual calculation for Spokane but only an example of the method. The point of this exercise is to demonstrate the general methods that can be used to permit a benefit-cost analysis to take account of the interdependencies among transportation noise abatement programs.

QUALIFICATIONS FOR THE PROPERTY-VALUE APPROACH

The primary objective in the adoption of property-value analysis as a means of estimating the benefits of noise abatement is to obtain figures, in dollars, directly comparable to those of the costs of abatement. By themselves, these benefit estimates are of interest as indicators of the magnitude of noise problems, but, more importantly, they are of value as input to other analytic techniques. (One of these, a cost-effectiveness analysis, was illustrated earlier in this chapter.) Their most common use is in cost-benefit analyses. These analyses are widely used in the formulation and evaluation of policy proposals. Chapter 9 contains two illustrative cost-benefit exercises, one for jet aircraft, the other for medium- and heavy-duty trucks. They serve as specific examples of the ways in which the property-value analysis and the consequent benefit estimates arrived at in this chapter can be used to provide information for and help in the evaluation of noise abatement proposals.

There are aspects of the property-value model that need further discussion. The Committee recognizes that the use of property values as the sole index of benefits is likely to lead to evaluations that are far from perfect. Yet, at least for the moment, no satisfactory measure of benefits calculated independently of market values is available to cost-benefit analysts.

The property-value approach, though it may work well or badly, is an attempt to put quantitative pecuniary magnitudes on the damages produced by noise on physical health, psychic well-being, and social behavior. A neighborhood in which noise damages hearing, causes lack of sleep, and leads to social disruption will be an undesirable neighborhood to live in and we would expect that to some degree this will be reflected in rents and property values. It must be emphasized that we are interested in the relation between noise and property values not because of any financial loss to property owners (which is just a transfer of wealth from one social group to another); we are interested in property values only to the extent that they reflect health, psychic, social and any other forms of real noise damage. However, there are differences among Committee members about the magnitudes of the likely errors of this approach in carrying out that task and even, in some cases, about the likely direction of those errors.

SOME QUALIFICATIONS REQUIRED FOR THE BENEFIT ESTIMATES

There are several problems involved in inferring estimates of the benefits of noise abatement from the estimates of noise-induced discounts in property values. These problems vary in seriousness and in the extent to which they suggest inaccuracies in the estimates. This section lists some of the major concerns but will not try to resolve them; for many of these issues, the arguments are moot, and for others, the discussion is too technical for a general-purpose report. The nature of these difficulties can be gathered from the following illustrative list of issues.

1. Some of the land affected by transportation noise is used for non-commercial and non-residential purposes such as schools, parks, or hospitals. Other land is used for streets and sewers. Some part of the damage of noise to users of these properties will already be reflected in depressed values of nearby homes—a worsening of schools does reduce the price of homes nearby. But not all such noise damage will be reflected in this way, and so some estimate of the residual damage to schools, hospitals, and other such properties should be incorporated into the property-value estimates of the benefits of noise abatement.
2. There are tax incentives to home ownership that induce house purchasers to spend more for housing than they otherwise would spend with their incomes. To the extent that they therefore pay a higher price for quiet than they otherwise would, the benefits estimates have to be adjusted downward.
3. If the effects of noise or of an abatement program lead people to move to obtain quieter dwellings, the cost of those moving activities must be deducted from the property-value estimates of benefits.
4. Often, the property-value calculations are used to estimate benefits expected at some future time. In these cases, a discount rate is used to translate figures for different dates into comparable units. However, the calculated values of the benefits can be affected very substantially by the number chosen for the discount rate, and there is no general agreement on the way this rate should be chosen.
5. The adoption of an abatement program confers benefits on those who own the property at the time, just as the original imposition of noise imposed costs on those who owned the property at that time. Similarly, the effects of noise or abatement may have different consequences for owners than for tenants. These considerations raise questions of distributive equity, which are ignored in the property-value method of benefit estimation even though they may be considered vital for policy decisions.
6. The property-value analysis estimates differentials in quiet and noisy residences. If noise is so pervasive as to affect all properties, the analysis may not be applicable. If the quietest location is noisy in

absolute terms, no quiet residences will be available for comparison and it may therefore not be possible to estimate willingness to pay for quiet.

7. Prices may reflect noise damage inadequately if buyers have very imperfect information about the magnitude and the effects of noise. If buyers are, for example, unaware that noise can produce deafness (and there are incentives for the sellers not to disseminate such information), buyers' willingness to pay for quiet may be different than if they are fully informed. There are undoubtedly some effects of noise about which little scientific evidence is now available, but which may be documented in the future. Current willingness to pay, and, consequently, current property value differentials, clearly cannot reflect noise damage that no one really knows about.

8. The use of property values to infer people's willingness to pay for quiet rests upon the assumption that there are no external constraints on people's choices. If there is discrimination on the part of mortgage lenders or realtors against particular racial, ethnic, or age groups, or if certain neighborhoods are red-lined, i.e., are disqualified for mortgage loans, the market mechanism will not operate freely, and the property-value estimates will be in error.

9. If rents or prices are determined or heavily influenced by an outside mechanism, such as a rent control law, the differences between quiet and noisy property will not reflect willingness to pay and the benefits estimates obtained from property-value analyses will be in error.

10. Statistical procedures must be used to disentangle the effects of noise on property values from the effects of all other variables influencing property values. This separation of influences becomes very difficult when the factors affecting property values—e.g., noise, proximity to airports, quality of schools, size of homes—are closely correlated, that is, when a change in one factor is usually accompanied by a similar change in some or all of the other factors. In cases where there are high degrees of colinearity, that is, where the movements in the variables are closely parallel, the calculated property-value discounts will be less reliable and the associated benefit estimates less stable and useful.

11. The inference that property price differentials are reflections of people's willingness to pay for quiet rests on assumptions on the nature of human choices. There are substantial differences of opinion on the extent to which fiscal decisions correspond to individuals' preferences. If there is large variation between the amount of quiet an individual is willing to purchase and the individual's preference for quiet, the estimates of benefits based on property values will not reflect those preferences.

VARIATIONS IN ESTIMATES

Tables 7.1 and 7.2 contain the estimates for marginal damage and percentage reduction in average property values obtained from a series of studies of jet aircraft noise. Table 7.3 contains similar estimates for highway noise. There is a large amount of variation in these estimates from study to study. It varies as a function of the economic, demographic, and social characteristics of the geographic area investigated, as well as with the data and techniques used by the investigator. For example, the study of aircraft noise by Paik (1972) uses data collected in 1960, when jet aircraft were recently introduced; these aircraft are different from the aircraft under consideration in the other six studies. There are similar problems in the studies of highway noise. The Gamble et al. study (1974) of Bogota (New Jersey) was conducted in an area with background noise of approximately 70 dB, which is considerably greater than that of the other areas studied, thereby influencing the location of the origin in the regression equation. (Background levels of NEF 25 for the aircraft studies and 50 dB(A) for the highway studies [the 2 figures are not quite equivalent] were assumed to be levels below which there is no noise effect—i.e., they are the origin of the regression line.)

It should be noted that the range of variation from study to study is large relative to the magnitude of the correction factors already discussed. For the seven studies of aircraft noise shown in Tables 7.1 and 7.2, the mean of the marginal damage estimates is -$214/NEF with a standard deviation of $167/NEF. (With the Paik study eliminated, the mean marginal damage estimate is -$156/NEF with a standard deviation of $75/NEF.) For the studies of highway noise shown in Table 7.3, the mean deviation estimate is -$183/NEF with a standard deviation of $207/NEF. (With the Bogota study eliminated, the mean deviation estimate is -$106/NEF with a standard deviation of $40/NEF.)

Similarly, the percentage reduction in average property values reported in Tables 7.1 and 7.2 has a mean of 0.75 percent with a standard deviation of 0.60 percent. (With the Paik study omitted, the mean is 0.54 percent and the standard deviation falls to 0.24 percent.) For highway noise, as reported in Table 7.3, the mean is 0.62 percent with a standard deviation of 0.72 percent. (With the Bogota study omitted, the mean is 0.35 percent with a standard deviation of 0.15 percent.)

This range of variation has been taken into account in Chapter 9, in which the benefit estimates have been used in cost-benefit analyses. In that chapter, the analyses used benefit estimates ranging from the largest value to about the mid-point of the calculated figures.

THE MAGNITUDES OF THE REQUIRED ADJUSTMENTS

The illustrative reservations listed above can obviously be of considerable significance, and they can make a considerable difference for the estimated values obtained from observation of real estate prices. Just for its suggestive value, we undertook some illustrative calculations in one or two cases where plausible guesses seemed possible. For example, a rough calculation based on the size of the relevant areas and the degree to which they are likely to be affected by noise suggests that the figure for the benefits of noise abatement obtained from a property-value calculation should be adjusted upward by between 2 and 15 percent to allow for benefits to schools, hospitals, and other properties that would not already be reflected in neighborhood property prices.

On the other hand, a similar hybrid between guesswork and analysis suggests that the tax advantage accorded to home ownership calls for a downward adjustment in the benefit figures of the real-estate calculation of between 8 and 10 percent.

These two figures are clearly not intended to be accepted literally, nor is their objective to suggest that the required upward and downward adjustments will approximately cancel out. Yet it is worth observing that (1) the required adjustments do not all go in the same direction; (2) they are not insignificant in size; (3) at this point, at best, we can offer only the roughest sort of evaluations of their magnitudes; and (4) for some of the adjustments we cannot even offer a reasonable conjecture about the amount involved.

IMPERFECT INFORMATION AND THE PROPERTY-VALUE ESTIMATE OF BENEFITS

The qualifications that have just been discussed include some that have rather technical aspects, of interest primarily to specialists. However, to illustrate the sorts of issues involved, we next examine in somewhat greater detail one of the qualifications—that relating to imperfect information on the part of purchasers of property.

One reason the difference in market values of quiet and noisy properties may not be the same as the true cost of the noise is that property buyers may simply not know at the time they make their purchases how noisy the property really is or not realize how serious the damaging effects of the noise will be. If at the time of purchase they think a noisy house is less noisy than it really is, or if they underestimate the resulting discomfort and damage to themselves and their families, they are likely to pay a higher price for the property than they would have otherwise. As a result, the market prices of noisy houses will be closer to the market prices of quiet houses and the property-value method will underestimate the true noise damage. On the other hand, the opposite will be true if home buyers overestimate noise damage—thinking it has more serious physiological consequences than it really does or believing that it will constantly disturb their sleep even though they may soon grow used to it.

Instinctively, one tends to believe that the first of these possibilities is more likely—that imperfect information will most frequently lead home buyers to underestimate the noisiness of their new homes and, therefore, that the property-value method will on this account be biased toward underestimation of the true cost of noise. After all, there is no motivation for sellers to exaggerate the noisiness of homes, and they do have much to gain by concealment of noisiness. For this reason, a number of members of this Committee are inclined to believe that imperfection of buyers' information requires an upward adjustment in the abatement benefit figures derived from property-value data.

However, it must be recognized that there is no firm evidence on this matter and the arguments on the other side are strong. It is at least possible that people imagine the degree of disturbance noise will cause them to be greater than it is. Some observers assert that in a number of cases this seems to have been true, with real estate values plunging temporarily in areas that were merely suspected to be under consideration as airport sites.

Those who question the view that buyers are systematically misinformed about noise point out that the discounts in the values of noisy property are reasonably consistent from city to city. For example, the effect of airplane noise, measured in dollars of lost property value per NEF, is roughly the same for such diverse cities as Boston, Minneapolis-St. Paul, and San Francisco. Furthermore, there is also some evidence to suggest that there is no relationship between noise and length of occupancy for owner-occupied housing (De Vany 1974) once other factors are taken into account. This suggests that few recent buyers are putting their homes back on the market, having discovered that their new property is noisier than they had believed at the time of purchase.

There are other arguments that can be adduced on both sides, but they would merely confirm our finding that the issue is far from settled.

CONCLUSION

A benefit-cost analysis provides no more than a reasonably well-defined starting point from which to begin an examination of proposed public programs, such as those designed to reduce noise and its effects. It is essential to proceed beyond mere benefit-cost calculations, to examine issues such as income-distribution effects, political and technical feasibility, legality, and overall social consequences. Cost-benefit techniques have only a limited capacity to incorporate information about social values, political effectiveness, or moral judgments—considerations that influence public decisions. It follows that an economic analysis, particularly one relying on surrogate measures such as property values to evaluate health, psychic, and social consequences, leaves a variety of judgments that must be made by the decision maker as an adjunct to the economic calculations. Decisions about noise abatement programs are also decisions about style and quality of life, about the social benefits of health and welfare, about government intervention in personal decisions, and about the relative value of short- and long-term effects. The cost-benefit analysis properly constitutes the beginning of the decision process, not its end.

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8

Costs of Noise Abatement

INTRODUCTION

There is a lack of information on the general costs of noise abatement except for a few types of vehicles: commercial aircraft (see FAA 1976), heavy and medium trucks (see U.S. EPA 1976), and locomotives (see U.S. EPA 1975) are the major exceptions. However, even for these vehicles there is a wide difference of opinion on the magnitude of some of the costs, the appropriate method of accounting for the costs, the meaning of the benefits derived, and the appropriate relationships among future costs and benefits.

Two basic types of cost-abatement programs merit particular emphasis: retrofitting (the installation of noise-reduction equipment to existing vehicles) and regulation of new vehicles. Retrofitting programs lend themselves to reasonably reliable cost estimates once the noise-reduction equipment has been designed and tested, as in the FAA programs. Cost estimates for regulatory programs are more difficult and suffer from considerable uncertainty, primarily because it is difficult to estimate the cost imposed by adding a noise performance requirement to the other performance requirements associated with the design of a new vehicle. Consequently, the approach often is based on the cost of adding noise-reduction equipment to a new vehicle of existing design, an approach that probably overestimates the real future cost by a significant margin.

Overall, the costs of noise abatement for transportation vehicles are significant. For surface vehicles, such as automobiles and trucks, this is largely attributable to the large number of vehicles involved; for example, with 10 million automobiles purchased every year, a $10 increase per new automobile yields a total cost of $100 million per year. For aircraft, the unit cost of abatement is very high; for example, a per-vehicle cost of $500,000 for 2000 aircraft yields a total cost of $1 billion.

The remainder of this chapter suggests the magnitudes of the costs associated with some proposed or possible noise abatement programs, with detailed examples for commercial aircraft. A variety of estimates of the costs of noise abatement are listed for commercial aircraft and for other vehicles that contribute to urban noise. The cost estimates are highly controversial and are presented in this report only to provide examples of the general magnitude of the costs that can be anticipated and that can be used in examples of cost-benefit analysis.

AIRCRAFT

EXPECTED TRENDS IN AIRCRAFT NOISE

When Federal Aviation Regulation Part 36 (FAR 36) was promulgated in 1969, it was expected that as new airplanes complying with the noise standards of FAR 36 entered the fleet (replacing those certificated before 1969), the noise near airports would diminish. Those expectations were encouraged by the certification of the DC-10 and L-1011 aircraft (whose noise levels are 13 to 18 decibels lower than those of the B-707 and DC-8 aircraft, which they were expected to replace), and between 1970 and 1973 total noise near airports was reduced. However, at the end of 1973 several events occurred that not only slowed the reduction in noise, but also reversed the trend. The oil embargo, accompanied by the general economic recession, led to a decrease in air travel, which in turn resulted in an increase in air transportation costs, excess capacity, declining industry profits, and, by 1975, net losses for the air carrier industry. In response, some airlines grounded their quieter wide-body airplanes in favor of the smaller, but noisier, narrow-body airplanes; other airlines sold their wide-body airplanes; and, in general, orders for newer, quieter airplanes were either deferred indefinitely or cancelled outright. Thus, by mid-1976, 7 years after the passage of FAR 36, only 22 percent of the U.S. air carrier fleet met the noise standards. It is now estimated that unless there is a drastic reversal of industry economic trends or specific federal action, some 48 percent of the air carrier fleet in 1990 will still not meet the noise standards of FAR 36.

Total noise exposure is a function of the absolute noise levels of the individual airplanes and the number of operations at any airport. In

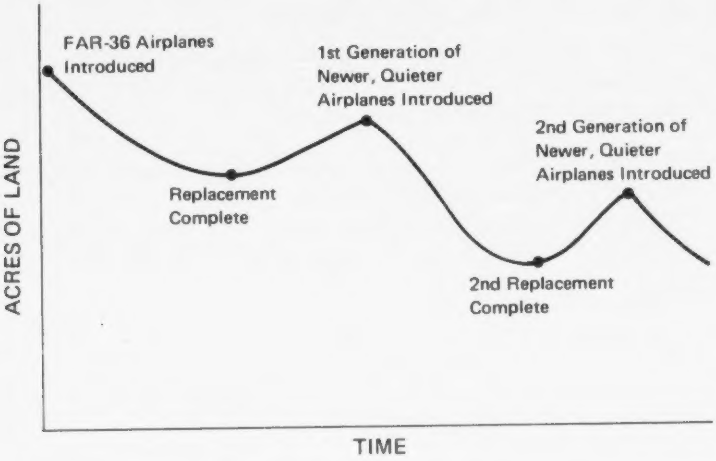

FIGURE 8.1 Cumulative noise exposure.

order to keep the cumulative noise level constant, a 3-dB reduction in aircraft noise levels is required for every doubling of operations. As a result, even if all of the new airplanes acquired in the future meet the standards of FAR 36, a short-term gradual reduction in cumulative exposure would eventually be reversed as the increase in operations will, once again, increase total exposure. Since airplanes are kept in service for 10 to 15 years (or longer if warranted) depending upon economic conditions, complete turnover of the fleet can take as long as 30 years.

Over the long run, therefore, one may expect a series of oscillations in cumulative exposure, with total exposure decreasing as newer, quieter airplanes replace older, noisier ones, and then, once replacement is complete, cumulative exposure increasing as the number of airplanes and operations increase until the next generation of airplanes is introduced and the cycle starts again. The increase in cumulative exposure will occur in two ways: a modest increase in exposure at current major airports, and the exposure of new populations near new and expanding airports. This is illustrated in Figure 8.1. Some of the predicted increase in cumulative noise exposure will come not only from an increase in operations, but also from the introduction of commercial jet aircraft to airports now served by propellor-driven aircraft.

MEASURES FOR REDUCTION OF AIRCRAFT NOISE

The immediate problem is how to reduce noise levels at a rate faster than shown in Figure 8.1. There are 4 major ways in which the noise emitted by airplanes can be reduced:

1. Retrofitting older, noisier airplanes with new engine nacelles containing sound absorbing material (SAM);
2. Replacing the engines of older airplanes with quieter engines that are fuel-efficient or modifying old engines as proposed in the REFAN program for JT8D engines (discussed in Chapter 7);
3. Accelerating replacement of older airplanes with quieter, more fuel-efficient airplanes using new technology; and
4. Modifying airplane operating procedures, including
    a. reduced thrust on takeoff and
    b. use of reduced flap/reduced thrust approaches.

In addition to these four ways to modify the airplanes themselves or the way they are operated, cumulative noise exposure near an airport can be reduced by changing airport operations or conditions near airports:

1. reducing the total number of operations;
2. limiting the number of operations of "noisy" airplanes;
3. reducing the number of night-time operations;
4. routing airplanes over nonresidential areas;
5. modifying land use regulations to permit only activities compatible with noisy airports; and
6. insulating homes to reduce interior noise levels.

COSTS OF AIRCRAFT NOISE ABATEMENT

The cost of reducing aircraft noise obviously depends on the per-unit cost, the number of airplanes affected, and the time period over which the program is conducted. In the case of aircraft, one of the important influences on the costs of noise abatement is the rate of retirement of older, noisier aircraft.

While the issues and programs to reduce noise can be concisely presented, the costs of each program vary with the assumptions and time period for which each action is proposed. Table 8.1 lists the number of aircraft of various types that did not meet the FAR 36 standards in 1976 and an estimate of the number of aircraft that will still not be in compliance with the standards in 1982. Table 8.2 reports the estimated

TABLE 8.1 Estimated Air Carrier Fleet Not Meeting FAR 36 Noise Standards, 1976 and 1982

Type	1976	1982
B-707, DC-8, B-720	487	391
B-727	572	459
B-737, DC-9	480	448
B-747	45	45
Total	1,584	1,343

SOURCE: FAA (1976:B-1)

costs of bringing these current aircraft into compliance with FAR 36. (These unit cost data are incorporated into the cost-benefit analysis in Chapter 9.)

From Table 8.2 we can observe that, on a unit-cost basis, REFAN modifications are substantially more costly than SAM retrofitting alone. For example, SAM retrofitting of a B-737—the most numerous type of aircraft not meeting FAR 36 standards—would require a capital outlay of about $0.27 million per aircraft compared with $1.92 million for a refanned engine in addition to the use of sound absorption materials. This implies that the incremental cost per aircraft per REFAN installation is $1.65 million ($1.92-$0.27). The total cost for the less expensive SAM retrofitting of the 1982 fleet of non-compliant aircraft listed in Table 8.1 is about $704 million (FAA cost estimates expressed in 1975 dollars).

MOTOR VEHICLES

MOTOR VEHICLE NOISE EMISSIONS

There are six types of surface vehicles that are important noise emitters: heavy trucks, medium trucks, light trucks, automobiles, motorcycles, and buses. Before the cost of the reduction of motor vehicle noise can be determined, the amount of noise emitted by each type of vehicle must be known. The magnitude of the sound produced by vehicles in each of these categories can be described in terms of noise energy emitted as they pass by 50 feet from a fixed monitoring point. Tables 8.3 through 8.8 describe these values for, respectively, heavy trucks, medium trucks, light trucks and automobiles, motorcycles, intercity transit buses, and school buses. In those tables, the regulatory levels for motor vehicles represent the maximum permissible noise levels under any mode of operation. A

TABLE 8.2 Estimated Costs per Aircraft to Comply with FAR 36 (Millions of 1975 Dollars)

Aircraft Type[1]	Capital Costs FAA Est.[2]	Capital Costs DOT Est.[3]	REFAN Lost Time Cost[4]	Percent Increase in Direct Operating Costs[5]	Percent Increase in Fuel Consumption[6]
SAM					
B-707	\$1.200[7]	\$1.200	\$0.094	0.5	0.2
DC-8	1.200[7]	1.020	0.102	0.6	0.2
B-727	0.225	0.225	0.	0.1	0.
B-737	0.270	0.264	0.	0.2	0.
DC-9	0.270	0.231	0.	0.1	0.
B-747	0.250	–	–	–	–
REFAN (Includes SAM)					
B-727	–	\$2.250	\$0.078	2.35	2.5
B-737	–	1.920	0.020	2.58	2.5
DC-9	–	1.270	0.028	2.52	0.5

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[1] SAM = Sound absorption material applied to engine nacelles.
REFAN = Refanned engines in JT8D-powered aircraft.

[2] FAA (1976:D-39).

[3] Bartel et al. (1974:2-112), converted to 1975 dollars.

[4] Bartel et al. (1974:2-116), converted to 1975 dollars.

[5] Bartel et al. (1974:2-117).

[6] Bartel et al. (1974:2-125).

[7] \$1.200 million per aircraft if 270 aircraft modified; 2.6 million per aircraft if 100 aircraft are modified.

vehicle must be designed, therefore, so that during some of its operation it will emit less noise than the maximum permissible in order not to exceed the standard when in its noisiest mode of operation. The test conditions used to collect the data for Tables 8.3 through 8.8, as described in those tables, result in baseline noise averages—current operations—and expected values under future regulatory levels of various degrees of severity.

Table 8.3 presents the noise data for heavy trucks. Noise emissions vary as a function of the operating conditions of the vehicle; the levels presented represent only a sample of the noise estimates that could be made. For example, more noise would be emitted if the trucks were traveling at higher speeds. Table 8.4 presents similar data for medium trucks.

Noise emission levels for automobiles and light trucks operating at 25 and 35 mph are described jointly in Table 8.5, along with the assumptions and conditions that underlie the estimates. Similar information for motorcycles is presented in Table 8.6, for intercity buses in Table 8.7, and for school buses in Table 8.8.

COSTS OF MOTOR VEHICLE NOISE ABATEMENT

The costs of abating motor vehicle noise vary with the severity of the regulatory standard desired: the more stringent the regulatory standard, the higher (usually) the cost of producing and operating the affected vehicles. The cost estimates in this section consider several alternative regulatory levels. These figures and their methods of calculation are described in Tables 8.3 through 8.8.

Heavy and Medium Trucks

Table 8.9 lists the annual production for 1976 and for 1984 of four types of truck—heavy and medium, gas and diesel.

The production and operating costs for the four types of trucks are shown in Table 8.10 for each of four regulatory levels of noise emission. For example, to attain a reduction of the noise emissions of heavy diesel trucks to an 83-dB(A) level would cost $185-$431 per vehicle. The lower of the two sets of estimates ("most likely capital costs") in Table 8.10 take into account the probable use of quieter engines and any decreases in manufacturing costs that may result from increased future production. Annual operating (maintenance and fuel) costs for heavy diesel trucks would increase approximately $48 per vehicle while the savings in operating costs would total $429.

TABLE 8.3 Estimated Energy Average Maximum Passby Noise Levels for Heavy Trucks at 50 ft at Urban Speeds[1]

	Operating Mode			Mixed[2]	
Regulatory Level	25-mph Cruise dB(A)	35-mph Cruise dB(A)	Acceleration dB(A)	25-mph Cruise dB(A)	35-mph Cruise dB(A)
None	80.9	81.9	86.6	82.8	83.3
83dB(A)	77.4	78.2	79.2	78.0	78.4
80dB(A)	74.7	76.2	76.4	75.8	76.2
75dB(A)	70.9	73.8	72.3	71.2	73.5

[1] For unregulated heavy trucks, the levels given in Table 8.3 for 25-mph cruise are based on survey data (Sharp 1974). The estimates for 35-mph cruise are based on the 25-mph data with an appropriate correction for tire noise, which is approximately 66 dB at 25 mph and 72 dB at 35 mph (Hornett and Williamson 1975). For cruising heavy trucks subject to noise emission regulations, the engine-related noise is assumed to be approximately 6.5 dB(A) below the regulatory level (National Bureau of Standards 1970); 2.5 dBA as a design tolerance for compliance with a not-to-exceed regulatory level, 3.0 dBA for differences in test and cruise modes of operation, and 1.0 dBA to compensate for differences in test and roadside sites. For accelerating heavy trucks, this procedure is repeated, except a 1.0-dBA difference is used for test and acceleration modes of operation. Regulations are assumed to be based on test procedures of the Society of Automotive Engineers (SAE), where passby noise levels are measured at 50 ft under wideopen throttle conditions.

[2] 20% acceleration and 80% cruise.

TABLE 8.4 Estimated Energy Average Maximum Passby Noise Levels for Medium Trucks at 50 ft at Urban Speeds[1]

Regulatory Level	Operating Mode 25-mph Cruise dB(A)	35-mph Cruise dB(A)	Acceleration dB(A)	Mixed[2] 25-mph Cruise dB(A)	35-mph Cruise dB(A)
None	74.3	76.4	78.6	79.6	76.9
83dB(A)	74.3	76.4	77.5	75.2	76.6
80dB(A)	73.4	75.5	76.4	74.2	75.7
75db(A)	70.9	73.8	72.3	71.2	73.5

[1] The data were estimated using the same set of assumptions described in Table 8.3 for heavy trucks. In cases where the level estimated from the regulatory level is higher than the level for existing medium trucks, the regulations are assumed to have no impact on the median passby level and the median level for existing medium trucks entered in the table. Regulations are assumed to be based on SAE test procedures, where passby noise levels are measured at 50 ft under wide-open throttle conditions.

[2] 20% acceleration and 80% cruise.

TABLE 8.5 Estimated Energy Average Maximum Noise Levels for Automobiles and Light Trucks at 50 ft[1]

Regulatory Level	Operating Mode 25-mph Cruise dB(A)	Operating Mode 35-mph Cruise dB(A)	Operating Mode Acceleration dB(A)	Mixed[2] 25-mph Cruise dB(A)	Mixed[2] 35-mph Cruise dB(A)
None	65.6	67.0	68.6	69.0	69.6
70dB(A)[3]	64.7	66.1	67.5	67.4	67.9
67dB(A)	60.2	63.5	65.5	63.5	64.6
65dB(A)	59.1	62.5	63.5	61.7	63.5

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[1] Existing automobiles and light trucks, accelerating and cruising at 35 mph, emit median levels of 68.6 and 67 dBA, respectively. For 25-mph cruising automobiles and light trucks, the 35-mph tire noise level is corrected to a speed of 25 mph, using 40 log V, where V is the vehicle speed. Since the noise levels measured according to the SAE J986a test procedure do not correlate well with the levels observed under typical operating modes, an energy-average multimodal test is assumed for regulations on noise emissions from automobiles and light trucks. The levels for the 35-mph cruise, 1/4-g acceleration, idle and wide-open throttle operating modes are selected such that the weighted energy-average is 2.5 dBA below each regulatory level in the table. The 25-mph cruise is computed by correcting the 35-mph tire noise level to a speed of 25 mph. Light trucks and automobiles measured under wide-open throttle conditions, such as specified in the SAE J986a test procedure, correlate poorly with passby levels measured under typical operating conditions (see Rentz, P. E. and L. D. Pope, Description and Control of Motor Vehicle Noise Sources. Vol. 2, Establishment of Standards for Highway Noise Levels, Final Report. Prepared by Bolt, Beranek and Newman, Inc. BBN Report 2739 for the Transportation Research Board, NCHRP 3-7/3, 1974). Therefore, the assumed regulations on light trucks and automobiles are based on a multimodal test in which a weighted energy-average of passby levels measured under different operating conditions is taken.

TABLE 8.6 Estimated Energy Average Maximum Passby Noise Levels for Motorcycles at 50 ft[1]

	Operating Mode			Mixed[2]	
Regulatory Level	25-mph Cruise dB(A)	35-mph Cruise dB(A)	Acceleration dB(A)	25-mph Cruise dB(A)	35-mph Cruise dB(A)
None	73.2	73.2	82.9	78.9	78.9
83dB(A)	72.1	72.1	79.0	75.7	75.7
80dB(A)	70.8	70.8	77.0	73.9	73.9
75dB(A)	66.4	66.4	71.0	68.5	68.5

[1] The estimated energy average levels for existing motorcycles operating in cruise and acceleration modes are 73.2 dBA and 82.9 dBA, respectively (private communication from S. Edwards, EPAIONAC, 23 June 1976). The same level is used for 25-mph and 35-mph cruise, since tire noise, the most speed-dependent noise component, is expected to be negligible. For regulated motorcycles, the energy average level under accelerating conditions is approximately 4 dBA below the regulatory level to allow for design tolerance to comply with a not-to-exceed regulatory level, differences in test and typical acceleration operational modes and compensate for differences in test and roadside sites. Regulations are assumed to be based on SAE test procedures, where passby noise levels are measured at 50 ft under wide-open throttle conditions.

[2] 33% acceleration and 67% cruise.

TABLE 8.7 Estimated Energy Average Maximum Passby Noise Levels for Intercity Transit Buses at 50 ft[1]

	Operating Mode			Mixed[3]	
Regulatory Level	25-mph Cruise[2] dB(A)	35-mph Cruise dB(A)	Acceleration dB(A)	25-mph Cruise dB(A)	35-mph Cruise dB(A)
None	76.4	N/A	81.5	N/A	79.6
83dB(A)	75.5	N/A	79.2	N/A	77.7
80dB(A)	74.7	N/A	76.4	N/A	75.6
75dB(A)	70.9	N/A	72.3	N/A	71.6

[1] The energy average maximum noise levels for existing intercity buses under accelerating conditions is 81.5 (Warnix 1974). The level for 25-mph cruise is estimated from 75 to 78 dBA 40-mph cruise noise levels by correcting the 40-mph tire noise to a speed of 25 mph (Motor Vehicle Manufacturers Association of the United States 1927-1976). The levels for regulated intercity buses are the same as the levels for regulated heavy trucks. Regulations are assumed to be based on SAE test procedures, where passby noise levels are measured at 50 ft under wide-open throttle conditions.

[2] Cruise includes deceleration.

[3] 50% acceleration and 50% cruise or deceleration.

TABLE 8.8 Estimated Energy Average Maximum Passby Noise Levels for School Buses at 50 ft[1]

	Operating Mode			Mixed[4]	
Regulatory Level	25-mph Cruise[2] dB(A)	35-mph Cruise[3] dB(A)	Acceleration dB(A)	25-mph Cruise dB(A)	35-mph Cruise dB(A)
None	74.3	76.4	81.9	79.6	80.0
83dB(A)	74.3	76.4	79.2	77.4	78.0
80dB(A)	73.4	75.5	76.4	75.2	76.0
75dB(A)	70.9	73.8	72.3	71.6	73.1

[1] The energy average maximum noise levels for existing school buses under accelerating conditions is 81.9 dB(A) (Warnix 1974). The level for 25-mph cruise is estimated from 75 to 78 dB(A) 40-mph cruise noise levels by correcting the 40-mph tire noise to a speed of 25 mph (Motor Vehicle Manufacturers Association of the United States 1927-1976). The levels for regulated school buses are the same as the levels for regulated medium trucks. Regulations are assumed to be based on SAE test procedures, where passby noise levels are measured at 50 ft under wide-open throttle conditions.

[2] Cruise includes deceleration.

[3] Cruise includes deceleration.

[4] 50% acceleration and 50% cruise or deceleration.

TABLE 8.9 Annual Production by Type of Truck, 1976 and 1984

	Thousands Produced	
Truck Type	1976	1984
Medium Gas	204	229
Heavy Gas	3	3
Medium Diesel	40	39
Heavy Diesel	165	248

SOURCE: U.S. EPA (1976:B-2).

The table indicates the rapidity with which costs mount as noise abatement becomes increasingly stringent. For example, a reduction in medium gas truck sound levels from 83 to 80 dB(A) is most likely to increase capital costs by $96 (from $11 to $107). But a reduction from 78 to 75 dB(A) is most likely to increase the cost by $251 (from $195 to $446).

When the production data presented in Table 8.9 are combined with the data on cost per vehicle in Table 8.10, the total annual costs, as displayed in Table 8.11, can be evaluated. The costs shown are sensitive to the assumptions concerning capital costs as well as to the regulatory level.

Light Trucks, Automobiles, Motorcycles, and Buses

The costs of noise abatement for other motor vehicles can also be estimated. Tables 8.12, 8.13, and 8.14 present data on the annual production of these vehicles, the per-unit production and operating costs, and the total annual costs for noise abatement. Table 8.12 presents these data for a regulatory level of 83 dB(A) for motorcycles and buses and 70 dB(A) for automobiles and light trucks; Table 8.13 for a regulatory level of 80 dB(A) for motorcycles and buses and 67 dB(A) for automobiles and light trucks; and Table 8.14 for a regulatory level of 75 dB(A) for buses and motorcycles and 65 dB(A) for automobiles and light trucks.

All Vehicles

The total annual national cost of compliance with each regulatory standard is shown in Table 8.15. Once again, the costs of compliance increase sharply with regulatory stringency. For the most stringent level—(70 dB(A) for automobiles and light trucks and 83 dB(A) for other vehicles)—there is even a possibility of a small net savings, but each

TABLE 8.10 Estimated Costs per Truck to Comply with Noise Emission Standards (1975 Dollars per Truck)

Truck Type/ Standard	Worst Case Capital Cost[1]	Most Likely Capital Cost[2]	Avg. Annual Maintenance Cost[1]	Avg. Annual Maintenance Cost (Saving)[1]	Avg. Annual Fuel Cost[1]	Avg. Annual Fuel Cost (Saving)[1]
Medium Gas						
83 dB(A)	$ 42	$ 11	$ 11	$ 0	$ 0	$ (53)
80 dB(A)	218	107	23	0	1	(95)
78 dB(A)	399	195	108	0	1	(126)
75 dB(A)	805	446	117	0	4	(126)
Heavy Gas						
83 dB(A)	$ 151	$120	$ 23	$ 0	$ 1	$(308)
80 dB(A)	309	218	45	0	2	(308)
78 dB(A)	460	334	131	0	2	(308)
75 dB(A)	866	586	162	0	7	(308)
Medium Diesel						
83 dB(A)	$ 516	$ 69	$ 59	$(66)	$ 3	$ (91)
80 dB(A)	1,029	207	96	(66)	9	(191)
78 dB(A)	1,283	405	298	(66)	15	(217)
Heavy Diesel						
83 dB(A)	$ 431	$185	$ 42	$(66)	$ 6	$(363)
80 dB(A)	713	328	104	(66)	15	(363)
78 dB(A)	1,042	385	167	(66)	18	(363)
75 dB(A)	1,651	770	280	(66)	62	(363)

[1] U.S. EPA (1976:D-2, D-3 and 6-25), converted to 1975 dollars. Assumes fan-off compliance testing for capital costs.

[2] U.S. EPA (1976:6-13, Table 6-6) converted to 1975 dollars.

TABLE 8.11 Costs of Producing and Operating Quieter Trucks (in 1975 million $ and 1976 production quantities)

Truck Type/Standard	Highest Capital Cost (Saving)	Most Likely Capital Cost (Saving)
Medium Gas		
83 dB(A)	0.0	(6.3)
80 dB(A)	30.0	7.8
78 dB(A)	77.9	36.3
75 dB(A)	163.2	90.0
Heavy Gas		
83 dB(A)	(0.4)	(0.5)
80 dB(A)	0.1	(0.1)
78 dB(A)	0.9	0.5
75 dB(A)	2.2	1.3
Medium Diesel		
83 dB(A)	16.8	(1.0)
80 dB(A)	35.1	2.2
78 dB(A)	52.5	17.4
Heavy Diesel		
83 dB(A)	8.3	(32.3)
80 dB(A)	66.5	3.0
78 dB(A)	131.7	23.3
75 dB(A)	258.1	112.7

increment of abatement becomes progressively more costly, reaching a likely capital cost of $700 million when auto and light truck noise is reduced to 65 dB(A) and that of other vehicles to 75 dB(A).

PATH ABATEMENT AND INSULATION

In addition to treatment of the source, noise can be abated by erecting barriers that interrupt the noise path or by insulating the receiver. This section briefly considers path and receiver treatment for noise produced by motor vehicles and receiver treatment for noise produced by aircraft.

COSTS OF PATH ABATEMENT

Vegetation

It is maintained by some that planting vegetation to a depth of 100 feet will reduce motor vehicle noise by 5-8 dB(A) (Reethof 1973; see also Beaton and Bourget 1973). There is considerable difference among experts as to the acoustical effectiveness of plantings, although the

TABLE 8.12 Estimated Annual Costs of Noise Reduction for Compliance with Regulatory Level of 83 dB(A) for Buses and Motorcycles and 70 dB(A) for Automobiles and Light Trucks

Vehicle Type	Total Population	Annual Production	Production Cost/Vehicle (1975 $)	Annual Operating Costs/Vehicle (1975 $)	Total Costs (1975 million $)
Intercity Bus[1]	23,000	2,500	237	39	0.7
School Bus[1]	310,000	33,500	23	9	1.1
Motorcycle 0-100 cc[2]	–	172,000	2	–	0.3
Motorcycle 100-200 cc[2]	–	282,000	10	–	2.8
Motorcycle > 200 cc[2]	–	543,000	21	–	11.4
Automobiles[3]	–	10,949,000	1	–	10.9
Light Trucks[3]	–	1,999,000	3	–	6.0

[1] The bus population estimates are taken from Warnix (1974). The annual production figures are estimated from a total annual bus production of 36,000 and the population percentage of each bus type. Because of the similarity of the noise treatments of buses and trucks, cost estimates comparable to those for heavy trucks are applied to intercity buses and the estimates for medium trucks applied to school buses.

[2] The estimates of motorcycle annual production are based on a total production of 1,000,000 (private communication from S. Edwards, EPA/ONAC, 23 June 1976) and a percentage of breakdown of 17.1 percent for 0-100 cc, 28.2 percent for 100-200 cc, and 54.3 percent for greater than 200 cc motorcycles (see Singh, J. and R. A. Renner, The Impact of Noise Abatement Standards upon the Motorcycle Industry. A Study by International Research and Technology Corporation for the Environmental Protection Agency, 1974, unpublished). Production costs are based on production cost estimates presented by Singh and Renner (see Singh, J. and R. A. Renner). No data are available on changes in operating costs for noise-treated motorcycles.

[3] The production estimates for automobiles and light trucks were obtained from Motor Vehicles Manufacturers Association of the United States (1919-1975). The production costs for light trucks regulated at the first level (70 dBA) and the second level (67 dBA) are sales-weighted averages of estimates given by Remington and Burroughs (see Remington, P. J. and C. B. Burroughs, Noise Control Technology for Light Trucks, BBN Interim Report No. 3252, 28 February 1976, unpublished). The estimate for the third regulatory level (65 dBA) is derived from the estimates for the first two levels. The cost estimates for automobiles were computed by multiplying the cost estimates for light trucks by the ratio of costs for light trucks and the costs for automobiles given by General Motors (Vehicular Noise Control Environmental Activities Staff 1973). Data are not available on changes in operating costs for noise-treated automobiles and light trucks.

TABLE 8.13 Estimated Annual Costs of Noise Reduction for Compliance with Regulatory Level of 80 dB(A) for Buses and Motorcycles and 67 dB(A) for Automobiles and Light Trucks)

Vehicle Type	Total Population	Annual Production	Production Cost/Vehicle (1975 $)	Annual Operating Costs/Vehicle (1975 $)	Total Costs (1975 million $)
Intercity Bus[1]	23,000	2,500	393	97	1.2
School Bus[1]	310,000	33,500	120	20	4.7
Motorcycle 0-100 cc[2]	–	172,000	4	–	0.7
Motorcycle 100-200 cc[2]	–	282,000	22	–	6.2
Motorcycle > 200 cc[2]	–	543,000	39	–	21.2
Automobiles[3]	–	10,949,000	15	–	164.2
Light Trucks[3]	–	1,999,000	25	–	50.0

[1] The bus population estimates are taken from Warnix (1974). The annual production figures are estimated from a total annual bus production of 36,000 and the population percentage of each bus type. Because of the similarity of the noise treatments of buses and trucks, cost estimates comparable to those for heavy trucks are applied to intercity buses and the estimates for medium trucks applied to school buses.

[2] The estimates of motorcycle annual production are based on a total production of 1,000,000 (private communication from S. Edwards, EPA/ONAC, 23 June 1976) and a percentage of breakdown of 17.1 percent for 0-100 cc, 28.2 percent for 100-200 cc, and 54.3 percent for greater than 200 cc motorcycles (see Singh, J. and R. A. Renner, The Impact of Noise Abatement Standards upon the Motorcycle Industry. A Study by International Research and Technology Corporation for the Environmental Protection Agency, 1974, unpublished). Production costs are based on production cost estimates presented by Singh and Renner (see Singh, J. and R. A. Renner). No data are available on changes in operating costs for noise-treated motorcycles.

[3] The production estimates for automobiles and light trucks were obtained from Motor Vehicles Manufacturers Association of the United States (1919-1975). The production costs for light trucks regulated at the first level (70 dBA) and the second level (67 dBA) are sales-weighted averages of estimates given by Remington and Burroughs (see Remington, P. J. and C. B. Burroughs, Noise Control Technology for Light Trucks, BBN Interim Report No. 3252, 28 February 1976, unpublished). The estimate for the third regulatory level (65 dBA) is derived from the estimates for the first two levels. The cost estimates for automobiles were computed by multiplying the cost estimates for light trucks by the ratio of costs for light trucks and the costs for automobiles given by General Motors (Vehicular Noise Control Environmental Activities Staff 1973). Data are not available on changes in operating costs for noise-treated automobiles and light trucks.

TABLE 8.14 Estimated Annual Costs of Noise Reduction for Compliance with Regulatory Level of 75 dB(A) for Buses and Motorcycles and 65 dB(A) for Automobiles and Light Trucks)

Vehicle Type	Total Population	Annual Production	Production Cost/Vehicle (1975 $)	Annual Operating Costs/Vehicle (1975 $)	Total Costs (1975 million $)
Intercity Bus[1]	23,000	2,500	909	276	3.0
School Bus[1]	310,000	33,500	443	101	16.9
Motorcycle 0-100 cc[2]	–	172,000	8	–	1.4
Motorcycle 100-200 cc[2]	–	282,000	30	–	8.5
Motorcycle > 200 cc[2]	–	543,000	60	–	32.6
Automobiles[3]	–	10,949,000	30	–	328.5
Light Trucks[3]	–	1,999,000	50	–	100.0

[1] The bus population estimates are taken from Warnix (1974). The annual production figures are estimated from a total annual bus production of 36,000 and the population percentage of each bus type. Because of the similarity of the noise treatments of buses and trucks, cost estimates comparable to those for heavy trucks are applied to intercity buses and the estimates for medium trucks applied to school buses.

[2] The estimates of motorcycle annual production are based on a total production of 1,000,000 (private communication from S. Edwards, EPA/ONAC, 23 June 1976) and a percentage of breakdown of 17.1 percent for 0-100 cc, 28.2 percent for 100-200 cc, and 54.3 percent for greater than 200 cc motorcycles (see Singh, J. and R. A. Renner, The Impact of Noise Abatement Standards upon the Motorcycle Industry. A Study by International Research and Technology Corporation for the Environmental Protection Agency, 1974, unpublished). Production costs are based on production cost estimates presented by Singh and Renner (see Singh, J. and R. A. Renner). No data are available on changes in operating costs for noise-treated motorcycles.

[3] The production estimates for automobiles and light trucks were obtained from Motor Vehicles Manufacturers Association of the United States (1919-1975). The production costs for light trucks regulated at the first level (70 dBA) and the second level (67 dBA) are sales-weighted averages of estimates given by Remington and Burroughs (see Remington, P. J. and C. B. Burroughs, Noise Control Technology for Light Trucks, BBN Interim Report No. 3252, 28 February 1976, unpublished). The estimate for the third regulatory level (65 dBA) is derived from the estimates for the first two levels. The cost estimates for automobiles were computed by multiplying the cost estimates for light trucks by the ratio of costs for light trucks and the costs for automobiles given by General Motors (Vehicular Noise Control Environmental Activities Staff 1973). Data are not available on changes in operating costs for noise-treated automobiles and light trucks.

TABLE 8.15 Cost of Compliance with Regulatory Noise Levels for 6 type of Vehicles: Automobiles, Light Trucks, Medium Trucks, Heavy Trucks, Motorcycles, and Buses

	Heavy and Medium Truck Capital Expenditure Assumption[1]	
Regulatory Level	Highest (1975 million $)	Most Likely (1975 million $)
Automobiles and Light Trucks: 70 dB(A) Other vehicles: 83 dB(A)	57.9	−6.9
Automobiles and Light Trucks: 67 dB(A) Other vehicles: 80 dB(A)	379.9	261.1
Automobiles and Light Trucks: 65 dB(A) Other vehicles: 75 dB(A)[2]	966.9	712.3

[1] 1976 production estimates.
[2] Medium diesel trucks at a level of 78 dB(A).

aesthetic value is undenied and may have an effect on people's attitude towards the noise emitter. However, the cost is not low. One estimate of the cost of planting a mixture of shrubs and trees is $7500 per 100 square feet or about $49,000 for a typical city block (Vaughan and Huckins 1975:46), exclusive of the costs of the land. In addition to its high cost, this method does not lend itself to widespread use because of space limitations in areas adjacent to highways.

Solid Barriers

Any solid barrier can serve as an effective noise attenuating device if it is tall enough to intercept the noise path. An earthberm that would reduce noise levels by 10 dB(A) costs between $17,000 and $29,000 per city block, depending on whether fill must be hauled to the site (Vaughan and Huckins 1975:48). A concrete wall that can reduce noise levels by 12-15 dB(A) costs $55-$75 per foot, or $36,000-$50,000 per city block. Aesthetics aside, use of an earthberm or concrete wall to reduce noise levels will depend on the initial noise levels, the site characteristics and alternatives, and the density and value of nearby residences.

COSTS OF INSULATION

The noise emitted by the commercial aircraft fleet can be abated by insulating receivers. Table 8.16 presents the costs of soundproofing all

TABLE 8.16 Estimated Cost of Insulation-Soundproofing all Residences[1] in NEF 30 Area by 1980

Noise Level Reduction	Total Cost (Billions of 1975 Dollars)
3-7 dB	1.9
8-12 dB	3.8
13-16 dB	7.2

[1] Sound proofing costs for residential dwellings vary with the type of construction, size of dwelling, materials used, and level of noise reduction to be attained. In this estimate, the first three variables were averaged.

SOURCE: Wyle Laboratories (1970).

residences currently within the NEF-30 contour for three levels of noise reduction. A program of insulation of residences, however, does not alleviate noise problems out-of-doors or inside of non-residential buildings.

CONCLUSION

This chapter has presented some estimates of the costs of noise abatement, primarily for treating commercial jet aircraft and motor vehicles. The costs have been estimated in monetary terms, suitable for use in other analytic techniques, such as the cost-benefit analyses illustrated in the next chapter. While many of the cost figures in this chapter must be treated as approximations, at best, there is far more agreement about the methods that should be used in estimating them than there is about the methods that should be used to calculate benefits.

The main conclusion that emerges from this chapter is that the cost of any significant noise abatement certainly will not be small.

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9

Cost-Benefit Analysis: Some Illustrations

INTRODUCTION

Cost-benefit analysis is a technique that assesses the probable gains from a proposed policy or action and weighs them against probable losses. It requires that both costs and benefits be measured in comparable terms; the usual standard of measurement is monetary. Quite often benefits are not directly expressible in terms of dollars, but have to be estimated indirectly through property values, compensation payments, court awards for damages, and the like.

The estimates for the benefits used for the cost-benefit analyses in this chapter, and by most economic studies of transportation noise, were obtained by multiple regression analyses of differences in property values. Thus, there are three particular techniques involved in these cost-benefit analyses: (1) the use of property values to estimate benefits; (2) the use of multiple-regression methods to calculate property-value differences; and (3) the cost-benefit analysis. However, use of the cost-benefit technique in general does not depend on property values or on multiple regression; it does not even depend on monetary estimates. For example, an elected official may choose to evaluate potential costs and benefits of a proposed policy in terms of votes for and against reelection. The particular cost-benefit analyses in this chapter, therefore, are illustrative both with respect to the specific examples of transportation noise and with respect to the specific type and method of estimating benefits.

There is a strong analytical basis for the conclusion that some noise abatement will yield benefits that exceed costs. That is, society must achieve net gains on balance from some amount of noise abatement. This is because noise emission, a by-product of economic activities, is damaging to society, but its emitters do not pay the social costs resulting from the damaging activities. As a result, one can be certain that noise emitters will find it in their financial interest to spend less for noise abatement than the amount required for maximization of the well-being of society. Thus, at least some increase in expenditures for noise abatement will be beneficial to society.[1]

While one can conclude that some noise abatement will be beneficial, one still has to determine just what programs will in fact yield benefits greater than their costs and which of the available alternatives would be most effective. This is the task that cost-benefit analysis is intended to carry out. Unfortunately, as will be illustrated in this chapter, data imperfection, problems of method, and other problems often prevent this method from yielding categorical conclusions.

As indicated in the previous chapters, the range of available noise abatement techniques and programs is very broad. Since the purpose of this chapter is to illustrate the application of benefit-cost analysis to transportation noise abatement, no attempt is made to provide a ranking of all possible programs for each transportation mode. Indeed, the state-of-the-art only permits the analysis in this chapter to cover five jet aircraft noise abatement projects which are not identified explicitly and four noise abatement programs for medium and heavy trucks. It also gives selected references to a few other benefit-cost studies, including analyses of projects not considered here.

The somewhat limited scope of the analysis in this chapter reflects in part the difficulty of benefit and cost measurements and the comparatively few studies that have so far been carried out. The analysis described here does not represent any original research by the Committee. The discussion does, however, attempt to provide evaluative comments on past studies where they seem appropriate.

[1] One may ask, however, whether it is really necessary for the state to intervene and require noise emitters to abate noise or to pay for their emissions. If there were only a few noise makers and a few sufferers, one might expect that they would be able to come to a voluntary agreement or contract about the appropriate amount of noise to be generated and the payments to be made for such amelioration of the environment. (This is the essence of the Coase Theorem; see Coase 1960.) Unfortunately, however, voluntary arrangements of this kind may not be possible in the abatement of noise. There are a very large number of sufferers—and in some cases (automobiles) a large number of emitters—and it is virtually impossible to bring these large numbers of people together in a voluntary agreement. The state does have a role to play.

The first step in a benefit-cost analysis is to select an indicator of achievement or success by which alternative projects can be ranked. Where the total budget for noise abatement projects is fixed, total expenditures should be distributed among projects so that no increase in total benefits can be achieved by an incremental reallocation from any one project to another. This requires a ranking based on the absolute differences between benefits and costs of the different projects after discounting for those costs and benefits that are expected in the more distant future. This criterion is referred to as the maximum net present value.

As an alternative criterion, projects are sometimes ranked by their benefit-cost ratio, defined as the present value of project benefits divided by the present value of project costs. It can be shown that the benefit-cost ratio will normally lead to a different and inferior set of choices, but this has not prevented its widespread use. The analysis in this chapter employs both of these criteria. Finally, no attempt has been made to extend the analysis to take actual budget constraints or other pertinent complications into account.

TYPES OF BENEFITS AND COSTS

It is hardly enough to say that all "relevant" or "pertinent" benefits and costs should be included in a benefit-cost analysis. The important problem is to decide which benefits and costs are relevant, whether or not they can be measured, and how they should be valued. Some aspects of this problem have been discussed in Chapters 6, 7, and 8, so that this section will only summarize briefly some of the issues involved. There is also the important issue of the distribution of the costs and benefits among different groups of the population. (Some parts of this issue are considered in Chapter 1 in this report.) Distribution issues are sometimes handled by the assignment of explicit weights to different groups of recipients, with benefits usually assigned higher weights if they go to poorer recipients. The analysis here only gives unweighted values for benefits and costs. (For an example of weighting in cost-benefit analysis of a noise abatement issue, see Nwaneri's study of the site for the Third London Airport [Nwaneri 1970]; see also Pearce and Wise [1972].)

REAL VS. PECUNIARY BENEFITS AND COSTS

Tables 9.1 and 9.2 list illustrative categories of benefits and costs that may be expected from aircraft and truck noise abatement projects, respectively. The tables only provide a few examples in each category. The

TABLE 9.1 Illustrative Benefits and Costs of Aircraft Noise Abatement[1]

Types	Benefits	Costs
Real		
Direct tangible	Reduction in hearing loss	Costs of inputs
intangible	Reduction in annoyance	Government intervention in local affairs
Indirect tangible	Improved worker productivity	Costs of regulation
intangible	Reduction in antisocial behavior	Disutility of household moving
Pecuniary	Relative improvement in the economic position of the aviation industry	Relative reduction in the economic position of commercial airlines

[1] The benefits and costs in this table merely illustrate the types of benefits and costs that can occur; it makes no attempt to be comprehensive.

TABLE 9.2 Illustrative Benefits and Costs of Truck Noise Abatement[1]

Types	Benefits	Costs
Real		
Direct tangible	Improved learning	Cost of inputs
intangible	Reduction in sleep loss	More complaints
Indirect tangible	Fuel savings	Costs of regulation
intangible	Reduction in antisocial behavior	Less masking of other noises
Pecuniary	Relative improvement in the economic position of equipment manufacturers	Relative reduction in the economic position of the trucking industry

[1] The benefits and costs in this table merely illustrate the types of benefits and costs that can occur; it makes no attempt to be comprehensive.

categories are designed to suggest some of the associated problems of relevance, ease of measurement, and valuation.

The first distinction suggested by Tables 9.1 and 9.2 is that between real and pecuniary costs and benefits. Real costs represent the use of physical resources required for the abatement of noise—the metal and fuel needed to produce abatement devices or insulation. Real benefits represent the increase in quiet to the consumers who no longer suffer as much physiological or psychological harm or annoyance as before. Pecuniary benefits and costs, on the other hand, are those resulting from price changes caused by a noise abatement project. For example, it may tend to raise the wages of skilled labor employed in retrofitting aircraft and to decrease the wages of, say, workers employed in the construction of insulated porches and double-glazed windows. The gains that accrue to some parts of society are offset by losses to other parts and generally represent neither a net gain or loss to society as a whole. Thus, employment or sales changes in the aerospace or airlines industries should not be included in an analysis of the real benefits and costs of aircraft noise abatement.[2]

DIRECT VS. INDIRECT BENEFITS AND COSTS

A second distinction suggested by Tables 9.1 and 9.2 is that between direct (primary) and indirect (secondary) benefits or costs, a distinction that is to some extent arbitrary. For example, the use of cooling fan clutches for the abatement of truck noise will yield an indirect benefit in fuel saving. It may also impose an indirect cost if truck operators are induced to avoid regulations by routing trucks over back roads to escape inspection. While indirect real costs and benefits are relevant, they are difficult to measure exhaustively since they are likely to be spread widely in the economy and to take unexpected forms.

TANGIBLE AND INTANGIBLE BENEFITS AND COSTS

The final distinction indicated in Tables 9.1 and 9.2 is that between tangible and intangible benefits and costs: tangible benefits and costs are those whose monetary value is observable directly; those whose monetary value cannot be observed directly are intangible. Noise abatement benefits are, by and large, intangible; consequently, they must be quantified by indirect procedures, which are more likely to give rise to serious measurement questions. The use of noise easements (see Baxter and Altree 1972) does approximate a market for quiet on a local level, although various special problems inhibit the use of this mechanism as a general basis for the valuation of the benefits of noise abatement.

At present, the only method that has been used systematically to measure the intangible benefits of noise abatement is based on observation of the association between residential property values (or apartment rents) and levels of environmental noise. This method, which assumes that the difference in the prices of properties in quiet and noisy neighborhoods reflects to some degree the valuation of quiet by the general public, has been described in detail and discussed critically in Chapter 7. Because no satisfactory substitute is, at least so far, available, it will be the basis for all of the quantification of noise abatement benefits in the next two sections of this chapter, with the exception of indirect fuel savings for trucks.

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[2] This reasoning may break down if there is widespread unemployment, so that every lost job represents a major loss to society as well as to the person directly affected. But a particular abatement project may not be the best way of using the unemployed. Unless their use in other projects is considered, the analysis may be seriously deficient.

ILLUSTRATIVE BENEFIT-COST ANALYSES OF AIRCRAFT NOISE ABATEMENT

This section illustrates the procedure that can be used to calculate the costs and benefits of commercial jet aircraft noise abatement projects. Whenever possible, an effort should be made to examine the sensitivity of the analysis to variations in some of the critical data whose values may be subject to question, and this, too, is illustrated in this section. A benefit-cost analysis accompanied by a sensitivity analysis not only shows a project's ranking, but also gives an indication of the extent to which the ranking will change as a result of changes in such variables as the state of the economy (e.g., the rate of economic growth, interest rates) or in the preferences of the policy maker (e.g., the implicit weight assigned to the employment or technological effect of a retrofitting program). This section examines two analyses of the benefits and costs of some aircraft noise abatement projects. (For additional examples, the reader is referred to Walters [1975], Council on Wage and Price Stability [1975a, 1975b], and FAA [1976].)

ILLUSTRATIVE ANALYSIS I

The first example of a benefit-cost analysis for jet aircraft noise abatement is based on the work of Nelson (1976), which is a revision of earlier work (Nelson 1975). It examines a policy of no change and three alternative programs, called A, B, and C.

The case involving no change in current noise abatement policy is defined as the baseline program; it is intended primarily as a standard of comparison for the other programs considered. (All noise abatement programs considered here reflect noise reductions resulting from thrust cutbacks on take-off.) Even with no change in policy, noise levels will decrease as the new, wide-body jets (B-747, DC-10, L-1011, and others) are introduced into the fleet and older, noisier jets are retired from commercial use. The baseline benefit estimate, reflecting the noise reductions expected from fleet mix changes, thus depends on a forecast of the rate of retirement of existing jets and levels of aviation activity in general.

Because the purpose of this chapter is to describe and comment on the techniques of benefit-cost analysis rather than to endorse any evaluation of some particular abatement procedure, we do not identify the three alternatives that will be described. All of them involved some modification in the operating procedures or the equipment used in older aircraft now in operation. Because of limitations of the data and because in each case some important considerations, such as the effect upon safety, are not taken into account, the figures as given could not be legitimately used as the basis for policy conclusions about the choice of noise abatement technique.

The general method used to calculate costs and benefits for each of the programs was described in Chapters 7 and 8. Since for each program the relevant costs are the additions in costs resulting from the introduction of the program, no cost estimates are needed for the baseline program. The types of cost included in the calculations were: (a) investment and installation costs required to carry out any modifications in equipment required by the three programs; (b) any lost flight time incurred during installation of any new equipment; and (c) any resulting direct and indirect increases in operating cost. Direct and indirect operating cost increases are taken to be incurred continually until the aircraft in question is retired from the fleet.

Benefit estimates were based on: (a) the estimated incremental reductions in noise exposure forecast (NEF) levels ascribable to each program; (b) an estimated incremental benefit per NEF of $175 per household in 1975, as indicated by real-estate values; and (c) an assumed increase in annual benefits per household of 3 percent per year from 1975 to 1987 and 2 percent per year from 1988 to 2001. The growth rate of incremental benefits is based on anticipated increases in average real incomes and increases in the willingness to pay for quiet.

Nelson examined the sensitivity of the benefit estimates to changes in the total population exposed to NEF 30+ and in the discount rate used to calculate present values for the period 1977-2001. For the year 1972, the size of the U.S. population exposed to NEF 30+ has been estimated to be 6.2 million (Safeer 1975:1). However, even with no policy changes, that number would have fallen to an estimated 6 million by the year 1976 as a result of the introduction of wide-body jets (FAA 1976:D-24). This figure is somewhat smaller than that found in several reports by EPA, and obviously excludes populations in the range of NEF 20-30.

Nelson's work also provides a sensitivity analysis of the discount rate used to translate future benefits and costs into current dollars. As alternatives, values of 4 percent and 8 percent were used for the real discount rate. (Real discount rates of 4 and 8 percent are equivalent to

TABLE 9.3 Total Discounted Costs and Benefits of Jet Aircraft Noise Abatement, 1977-2001, at $175 Per NEF in 1975 (Millions of 1975 Dollars)[1]

Abatement Program	Costs	Benefits	Benefits less Costs	Benefits Costs
At a 4% Real Discount Rate Until the Year 2001				
Baseline (No-Change)	–	$1,708.5	–	–
Program A	$ 77.6	370.6	$ 293.0	4.78
Program B	726.4	643.5	(82.9)	0.89
Program C	2,769.5	1,696.5	(1,073.0)	0.61
At an 8% Real Discount Rate Until the Year 2001				
Baseline (No-Change)	–	$1,097.1	–	–
Program A	$ 70.3	237.5	$ 167.2	3.38
Program B	602.9	467.6	(135.3)	0.78
Program C	2,068.9	1,161.7	(907.2)	0.56

[1] Discounted marginal benefits are $175 per NEF per household in 1975 based on an average $25,000 property value and a noise discount of 0.7 percent per NEF per property.

SOURCE: Based on Nelson (1976)

market interest rates of about 8 and 12 percent, respectively, when the rate of inflation is about 4 percent per year.) Current policies of the U.S. Office of Management and Budget call for a 10-percent market interest rate for evaluation of public projects (U.S. OMB 1969).

Table 9.3 shows estimated total discounted benefits and costs for the period 1977-2001 in constant 1975 dollars. For program A, estimated benefits always exceed costs while for programs B and C costs always exceed benefits in all our illustrative calculations. The sensitivity analysis reveals that the absolute differences between benefits and costs are indeed sensitive to changes in the choice of the real discount rate.

The sensitivity analysis can be extended by varying the estimate of the incremental benefit of noise abatement. Table 9.3 uses an estimate of $175 per household per NEF, based on an average property value of $25,000 in 1975 and a noise discount of 0.7 percent per NEF. The evidence (see Chapter 7) from past empirical studies suggests a noise discount for property values in the range of 0.4-1.0 percent per NEF, although at least two studies have yielded discounts in excess of 1 percent for areas near some airports (e.g., Paik 1972, Dygert 1973). The sensitivity of the analysis to variations in this parameter can be examined by multiplying the benefit estimates in Table 9.3 by the appropriate ratio of

TABLE 9.4 Total Discounted Costs and Benefits of Jet Aircraft Noise Abatement, 1977-2001, at $250 Per NEF in 1975 (Millions of 1975 Dollars)[1]

Abatement Program	Costs	Benefits	Benefits less Costs	Benefits Costs
At a 4% Real Discount Rate Until the Year 2001				
Baseline (No-Change)	–	$2,440.6	–	–
Program A	$ 77.6	530.0	$452.4	6.83
Program B	726.4	919.2	192.8	1.27
Program C	2,769.5	2,423.5	(346.0)	0.88
At an 8% Real Discount Rate Until the Year 2001				
Baseline (No-Change)	–	$1,567.2	–	–
Program A	$ 70.3	339.6	269.3	4.83
Program B	602.9	668.0	65.1	1.11
Program C	2,068.9	1,659.5	(409.4)	0.80

[1] Discounted marginal benefits are $250 per NEF per household in 1975 based on an average $25,000 property value and a noise discount of 1.0 percent per NEF per property.

SOURCE: Based on Nelson (1976)

noise discounts, e.g., 1.0/0.7 = 1.43 or 0.4/0.7 = 0.57. Table 9.4 shows the estimates of total discounted benefits and costs when the discounted benefits of abatement are $250 ($25,000 × 0.01) per NEF per household in 1975. It shows, for example, that for program B, benefits would now exceed costs. In other words, any ranking of noise abatement projects is quite sensitive to estimates of the discounted benefits. This parameter is crucial to the policy decisions to be reached with respect to aircraft noise abatement.

ILLUSTRATIVE ANALYSIS II

The benefit-cost calculations in Tables 9.3 and 9.4 use a baseline forecast for aviation activity that is somewhat out of date for the near future. As the rate of aggregate economic growth declined in 1973-75, so did the rate at which commercial aircraft were retired from the fleet. Assuming that this pattern will continue in the future, it means that noisier, narrow-body jets will be continued in use somewhat longer than is assumed in Tables 9.3 and 9.4.

The effect of a reduction in aircraft replacement is to increase, perhaps significantly, the benefits from the abatement programs relative to the

TABLE 9.5 Assumed Incremental Reductions in the Noise Exposure Forecast (Δ NEF) under Program B 1977-1995, Under Slower Retirement of Existing Aircraft

	Δ NEF				
	1977	1980	1985	1990	1995
Abatement Program B	0.0	-0.2	-0.9	-0.8	-0.1

SOURCE: FAA (1976:D-33).

revised baseline program. If more narrow-body jets are in use in each year, the incremental reduction in noise levels achievable by the abatement program will be greater and will extend over a longer period of time. At the same time, direct and indirect operating costs will increase as a result of physical obsolescence. These cost increases, however, will not result in any further reductions in noise levels and, indeed, one would expect the acoustical efficiency of the abatement programs to decrease somewhat over time, so that the outlays required for a given reduction in noise will increase. Consequently, it is not legitimate to conduct a sensitivity analysis in this case by just varying the benefit estimates while leaving the cost estimates unchanged.

We can examine the sensitivity of the earlier analysis to such changes in fleet mix, accompanied, for the sake of illustration, by the assumption that the number of aircraft to which abatement programs apply is simultaneously reduced. For this calculation several assumptions are made:

1. Program B affects 6 million people or about 2 million households over the period 1976-2001.

2. The reductions in the noise exposure forecast (Δ NEF) are based on the most recent FAA data and are shown in Table 9.5 for program B. The assumed incremental reductions in NEF values for program B are shown in Table 9.5, using the most recent FAA data.

3. The marginal capitalized benefit of a unit reduction in NEF is $175 per household in 1975 dollars. Annual benefits per household increase at 3 percent per year from 1975 to 1987 and 2 percent per year from 1988 to 2001.

4. Direct and indirect operating costs (in constant 1975 dollars) increase after 1990 as a result of the continued operation of the fleet and cost increases due to physical obsolescence. These increases occur despite the more modest program contemplated here: it is assumed that 1217 jets will be encompassed by the program between 1979 and 1986.

TABLE 9.6 Example of Discounted Costs and Benefits Under Slower Retirement of Existing Aircraft, 1977-2001 (Millions of 1975 Dollars)[1]

Abatement Program	Costs	Benefits	Benefits less Costs	Benefits Costs
	At a 4% Real Discount Rate Until the Year 2001			
Baseline	–	$ 34.9	–	–
Program B	$609.1	$319.9	$(289.2)	0.53
	At an 8% Real Discount Rate Until the Year 2001			
Baseline	–	$ 37.8	–	–
Program B	$492.3	221.6	$(270.7)	0.45

[1] Discounted marginal benefits are $175 per NEF per household in 1975 based on an average $25,000 property and a noise discount of 0.7 percent per NEF per property.

SOURCE: Based on Nelson (1976)

The net effect of these assumptions is to reduce both the benefits and costs of the abatement programs, although it should be pointed out the assumptions must be offered with somewhat stronger reservations than those applicable to Tables 9.3 and 9.4.

Using alternative real discount rates of 4 and 8 percent, the present values of costs and benefits were determined and shown in Table 9.6. This illustrates the basic point to be derived from this analysis: a more modest abatement program and a slowdown in the rate of attrition of existing aircraft will change both the incremental benefits and costs of such a program. As a result, this parameter (rate of attrition) turns out to be less crucial to the ranking of projects than the noise discount or interest rate. Table 9.6 shows that the calculated benefits of programs B and C still do not exceed the calculated costs despite the assumed continuation of slowdown in retirements. Indeed, this would be the case even at the higher marginal benefit of $250 per NEF per household.

BENEFIT-COST ANALYSES OF TRUCK NOISE ABATEMENT

This section examines two studies of the benefits and costs of the abatement of noise from medium and heavy trucks. (For analyses of other selected projects, the reader is referred to Merewitz [1975], Vaughan and Huckins [1975], and the Illinois Institute for Environmental Quality [1976] and the DOT 1975 projections[3].) Before examining the study by Nelson (1975) and an extension of a study by the Council on Wage and Price Stability (1975c, 1975d) two preliminary issues are discussed briefly.

An analysis of the benefits and costs of truck noise abatement involves greater uncertainty than a similar analysis of aircraft noise. In part, this is a result of the limited information available on the benefits of truck noise abatement, but it also reflects the great variety of trucking equipment and the complexity of the urban/suburban noise milieu. It is not clear, for example, that a reduction in truck noise will result in a corresponding reduction in annoyance, especially if other major sources of noise in residential areas are left unchanged. For this reason, the benefit analysis employs a wide range of possible values for marginal abatement benefits.

Unlike the case of aircraft/airport noise, it is not entirely clear that the benefits of abating urban/suburban truck noise can be analyzed by considering only those properties immediately affected—the property values near major highways and streets. Because so many areas are affected substantially, significant changes in urban/suburban truck noise levels would undoubtedly produce general changes in residential property values. The analyses that follow ignore these marketwide changes in property value as well as other analogous complications.

As a consequence of these two factors, the benefit-cost estimates in this section are subject to fairly large and undetermined probable errors, although this does not mean that tentative project ranking cannot be derived from the studies. The uncertainty in the calculation does, however, imply that any project ranking is subject to less confidence than might be the case for aircraft noise abatement. The benefit-cost calculations that follow are provided to indicate the current state-of-the-art and certainly do not constitute the last word on this subject.

ILLUSTRATIVE ANALYSIS I

The first example of a benefit-cost analysis of medium and heavy truck noise is provided by Nelson (1975). This study used population and noise level projections from a preliminary report by EPA (1974a) to calculate truck noise abatement benefits from residential property values. Cost estimates were also obtained from the EPA report.

EPA has identified medium and heavy trucks with a gross vehicle weight rating (GVWR) in excess of 10,000 pounds as a major source of noise (see 39 *Federal Register* 38338 1974). Four alternatives, including three noise abatement programs for these vehicles, were considered in this benefit-cost analysis.

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[3] U.S. Department of Transportation, Office of Noise Abatement (1975) Comparative Benefits and Costs Projected for Proposed New Medium- and Heavy-Duty Truck Noise Emission Standards. Washington, D.C.: U.S. Deprtment of Transportation. (Unpublished)

Baseline. The baseline assumes use of current operating rules. The Interstate Motor Carrier Noise Emission Standards (U.S. EPA 1974b) requires that all motor vehicles above 10,000 pounds GVWR operated by motor carriers engaged in interstate commerce meet the following standards as of October 1975:

a. No more than 86 dB(A) at 50 feet in speed zones at or under 35 mph under all conditions, and

b. No more than 90 dB(A) at 50 feet in speed zones over 35 mph under all conditions.

Abatement Program 1. This program requires new trucks of over 10,000 pounds GVWR not to exceed the following noise levels after October of the year indicated:

a. 1976	83 dB(A)
b. 1980	80 dB(A)
c. 1982	75 dB(A)

Abatement Program 2. This program has the same noise levels as the previous one, but with different effective dates:

a. 1976	83 dB(A)
b. 1977	80 dB(A)
c. 1980	75 dB(A)

Abatement Program 3. This program sets separate standards for gas-engine and diesel-engine powered trucks with the following effective dates:

	Gas	Diesel
a. 1976	80 dB(A)	83 dB(A)
b. 1977	80 dB(A)	83 dB(A)
c. 1980	75 dB(A)	83 dB(A)
d. 1980	75 dB(A)	80 dB(A)
e. 1982	75 dB(A)	75 dB(A)

Incremental cost estimates for each noise level were obtained from the

EPA report (1974a:7-29) for each noise level standard—83, 80, and 75 dB(A). The cost totals include depreciation, interest, and operating and maintenance expenses for the first full year during which the limits on noise levels become effective. Total costs were assumed to increase at 5 percent per year for 1976-1985 (Nelson 1975:10-15), reflecting the growth of new truck sales. Thereafter, the estimate of the incremental annual costs ascribable to the 75 dB(A) standard was fixed at $185 million per year.

Benefits from the abatement of truck noise were calculated in a manner analogous to the procedures used for aircraft noise benefits. For 1976-1992, the EPA report (1974a:6-20-21) indicated the reduction in the Day-Night Noise Levels (L_{dn}) in dB(A) (relative to 1974) and the equivalent number of people exposed to L_{dn} 55+ for each abatement program. The analysis assumes that a 1-dB(A) reduction in noise levels would result in a marginal capitalized benefit of $64 per household. Total benefits were assumed to grow at 5 percent per year for 1977-1983, but after 1983 benefits were extrapolated linearly, so that maximum total benefits were assumed to be attained in 1992.

Using these procedures, annual costs and benefits were calculated for 1977-2000 and then discounted to 1976 using real discount rates of 5 and 10 percent. (These rates correspond to market interest rates of approximately 9 and 14 percent, respectively.) Tables 9.7 and 9.8 show the basic results where the low-benefit estimate is based on a gradual decrease in the relevant population as some individuals are no longer exposed to L_{dn} 55+. The high-benefit estimate is based on an equivalent residential population in 1974 of 37.3 million (U.S. EPA 1974a:6-20). Tables 9.7 and 9.8 show that Programs 1 and 2 are the top-ranked projects using a 5-percent real rate of interest. However, any ranking will be sensitive to the population affected by truck noise abatement since the low-benefit estimate always yields a negative net present value.

The sensitivity of the analysis may again be examined for changes in the estimated marginal benefits of noise abatement. The analysis in Chapter 7 suggests a noise discount for traffic noise that varies between 0.2 and 0.6 percent per dB(A) for an average residential property. In 1975, the average residential property in the United States had a value of about $25,000. This implies that marginal capitalized damages from traffic noise range from about $50 to about $150 per dB(A), with a mean of about $100 per dB(A). Thus, Table 9.7 is based on a value near the lower limit of this range.

Table 9.8 shows the benefit-cost estimates when marginal capitalized benefits are assumed to be $100 per dB(A) per household. This table shows that higher benefit values will affect the ranking of projects, so that

TABLE 9.7 Total Discounted Costs and Benefits of Truck Noise Abatement, 1976-2000, at \$64 per dB(A) in 1975 (Billions of Dollars)[1]

Abatement Program	Costs	High Benefits[2]	Low Benefits[2]	High Benefits less Costs	High Benefits Costs
		At a 5% Real Discount Rate Until the Year 2000			
Baseline	–	\$1.60	\$1.30	–	–
Program 1	\$1.80	1.90	0.90	\$0.10	1.06
Program 2	2.10	2.10	1.00	(0.00)	1.00
Program 3	1.80	1.90	0.90	0.10	1.06
		At a 10% Real Discount Rate Until the Year 2000			
Baseline	–	\$1.00	\$0.80	–	–
Program 1	\$1.00	0.90	0.50	(\$0.10)	0.90
Program 2	1.20	1.10	0.50	(0.10)	0.92
Program 3	1.00	0.90	0.50	(0.10)	0.90

[1] Discounted marginal benefits are \$64 per dB(A) per household.

[2] The range of benefit estimates reflects alternative assumptions about the total equivalent population that is exposed to high levels of environmental noise, i.e., $L_{dn} > 55$ dB(A).

SOURCE: Based on Nelson (1975)

Program 2 then receives the highest ranking according to the criterion of maximum net present value. Program 2 uses an earlier time schedule, imposing the 75 dB(A) standard in October 1980 rather than October 1982. This advanced time schedule is reflected in the present values of both costs and benefits. The greater the residential damages due to noise, the more there is to be lost by postponement of the 75 dB(A) standard until 1982.

ILLUSTRATIVE ANALYSIS II

The analysis in this section parallels that contained in two reports prepared by Robert L. Greene for the Council on Wage and Price Stability (1975c, 1975d). These reports provide explicit and more up-to-date information on truck noise abatement costs. In addition, Greene estimated indirect abatement benefits arising from truck fuel savings ascribable to the use of a demand-actuated fan clutch, reduced back pressure in the exhaust system, less restrictive air intakes, and lower horsepower ratings. Most of the fuel savings are due to the fan clutch.

TABLE 9.8 Total Discounted Costs and Benefits of Truck Noise Abatement, 1976-2000, at $100 per dB(A) in 1974 (Billions of 1975 Dollars)[1]

Abatement Program	Costs	High Benefits[2]	Low Benefits[2]	High Benefits minus Costs	High Benefits Costs
	At a 5% Real Discount Rate Until the Year 2000				
Baseline	–	$2.50	$2.03	–	–
Program 1	$1.80	2.97	1.41	$1.17	1.65
Program 2	2.10	3.28	1.56	1.18	1.56
Program 3	1.80	2.97	1.41	1.17	1.65
	At a 10% Real Discount Rate Until the Year 2000				
Baseline	–	$1.56	$1.25	–	–
Program 1	$1.00	1.41	0.78	$0.41	1.41
Program 2	1.20	1.72	0.78	0.52	1.43
Program 3	1.00	1.41	0.78	0.41	1.41

[1] Discounted marginal benefits are $100 per dB(A) in 1974 based on an average $25,000 property and a noise discount of 0.4 percent per dB(A) per property.

[2] The range of benefit estimates reflects alternative assumptions about the total equivalent population that is exposed to high levels of environmental noise, i.e., $L_{dn} > 55$.

SOURCE: Based on Nelson (1975)

Greene examined the variation in benefits and costs as the severity of noise level standards is varied. Total benefits can, of course, be expected to increase as noise levels are reduced, but beyond some point the rate of increase in total benefits from additional quiet can be expected to decline. Total costs of increased abatement, on the other hand, can be expected to increase continually since it becomes more and more difficult to achieve an additional increment of quiet with current technology.

This incremental information permits an analysis beyond the usual cost-benefit results that, in effect, grade any proposed project on a pass-fail basis. Instead, with incremental data, one can determine the degree of abatement that yields maximal net social benefits. This analysis, based on the most recent data to be found in the EPA report, *Background Document for Medium and Heavy Truck Noise Emission Regulations* (U.S. EPA 1976), examines four alternative abatement projects.

Project 1. Under this project, new trucks over 10,000 pounds GVWR would be required not to exceed 83 dB(A) in 1978, with no further reductions required after that date.

Project 2. This project requires a standard of 83 dB(A) in 1978, 80 dB(A) in 1982, and no further reductions thereafter.

Project 3. This project requires a standard of 83 dB(A) in 1978, 78 dB(A) in 1984, and no further reductions thereafter.

Project 4. This project requires a standard of 83 dB(A) in 1978, 80 dB(A) in 1982, and 75 dB(A) in 1984 and thereafter. This project is essentially the same as Program 1 in Tables 9.7 and 9.8 ("Illustrative Analysis I," above) except that the time schedule is retarded by about 15 months.

The EPA data can be used to examine the incremental or marginal costs and benefits of an increasingly severe noise emission standard. This important issue is largely ignored in Tables 9.7 and 9.8, where only the marginal costs and benefits of an advance in the abatement time schedule are considered.

The benefits considered in this analysis include changes in residential property values that result from reduced noise levels and fuel savings that will result from abatement equipment or hardware. Property value benefits reflect: (a) a marginal capitalized damage cost of $50-$150 per dB(A) per household, based on an average $25,000 property value and a noise discount of 0.2-0.6 percent per dB(A); (b) a growth rate for real benefits of 3 percent per year for 1975-1987 and 2 percent per year for 1988-2000; and (c) equivalent populations of 31.4 million in urban areas and 2.6 million in suburban areas for 1978 and beyond. Annual fuel savings per truck are based on EPA data (1976:6-23) and assume average fuel prices per gallon of $0.60 for gasoline and $0.45 for diesel fuel in 1975. Total indirect benefits were determined from projected data on new truck sales and annual mileages, accumulated over four classes of trucks.

Costs include the capital costs incurred in equipping the quieter trucks and the increased maintenance and operating costs of the additional equipment. Total capital costs are based on a so-called worst case and on average values for four classes of trucks (U.S. EPA 1976:6-3, 6-7) adjusted to 1975 dollars, and projected data on new truck sales adjusted for higher prices. Maintenance and operating expenses are obtained directly from Appendix E of the EPA report.

Discounted costs and benefits are summarized in Tables 9.9 and 9.10, respectively. Various net-benefit estimates were then calculated and these estimates are shown in Table 9.11. The top-ranked project in all cases is Project 1, which imposes an 83 dB(A) standard in 1978. Note that net benefits fall when the 80, 78, or 75 dB(A) standards are imposed. This

TABLE 9.9 Total Discounted Costs of Truck Noise Abatement, 1977-2000 (Billions of 1975 Dollars)

	Capital Costs			Totals	
Abatement Program	(1) Low[1]	(2) High[2]	(3) Op. & Mnt. Costs[3]	(4) Low	(5) High
	At a 4% Real Discount Rate Until the Year 2000				
Baseline	–	–	–	–	–
1 - 83 dBA	$2.2	$2.4	$1.5	$ 3.7	$ 3.9
2 - 83/80	3.8	4.4	3.2	7.0	7.6
3 - 83/78	5.2	5.7	5.4	10.6	11.1
4 - 83/80/75	8.3	8.8	8.4	16.7	17.2
	At an 8% Real Discount Rate Until the Year 2000				
Baseline	–	–	–	–	–
1 - 83 dBA	$1.4	$1.5	$0.9	$2.3	$ 2.4
2 - 83/80	2.4	2.8	1.9	4.3	4.7
3 - 83/78	3.2	3.5	3.0	6.2	6.5
4 - 83/80/75	5.0	5.3	4.7	9.7	10.0

[1] Based on unit cost data in U.S. EPA (1976:6-14).
[2] Based on unit cost data in U.S. EPA (1976:6-3).
[3] Derived from Appendix E of U.S. EPA (1976).

suggests that marginal costs exceed marginal benefits for these projects, although in almost all cases the benefit-cost ratio would exceed 1. For example, Table 9.9 shows that the 80 dB(A) standard has a marginal cost of $3.3 billion ($7.0 billion minus $3.7 billion) when the low estimate of total costs is employed, while Table 9.10 shows a marginal benefit of only $1.5 billion ($17.3 billion minus $15.8 billion) of 1975 dollars. Furthermore, these results hold over the range of property value effects considered, $50-$150 per dB(A) per household. Thus, unlike the analysis for aircraft noise abatement, the results here are not particularly sensitive to measures of intangible, direct benefits based on the property value method. The increase in property values is, by itself, insufficient to offset the increase in costs arising from the more stringent standards, given the small increase in fuel savings at standards below 83 dB(A).

Manufacturers, however, have indicated that it may be possible to meet the 83 dB(A) standard without the installation of a fan clutch, depending on testing procedures and the timetable for noise reductions. In this event, fuel savings at 83 dB(A) might be minimal and a more stringent noise standard would be required to attain the significant indirect benefits associated with this hardware. It is possible that most of

TABLE 9.10 Total Discounted Direct and Indirect Benefits of Truck Noise Abatement, 1977-2000 (Billions of 1975 Dollars)

		Consumer Benefits		Totals	
Abatement Program	(6) Op. & Mnt. Savings[1]	(7) Low[2]	(8) High[3]	(9) Low	(10) High
		At a 4% Real Discount Rate Until the Year 2000			
Baseline	–	$0.8	$2.5	$ 0.8	$ 2.5
1 - 83 dBA	$15.0	0.8	2.5	15.8	17.5
2 - 83/80	16.0	1.3	3.9	17.3	19.9
3 - 83/78	16.4	1.4	4.1	17.8	20.5
4 - 83/80/75	16.4	1.6	4.9	18.0	21.3
		At an 8% Real Discount Rate Until the Year 2000			
Baseline	–	$0.5	$1.7	$ 0.5	$ 1.7
1 - 83 dBA	$ 9.7	0.5	1.5	10.2	11.2
2 - 83/80	9.8	0.8	2.3	10.6	12.1
3 - 83/78	10.0	0.8	2.4	10.8	12.4
4 - 83/80/75	10.0	1.0	2.9	11.0	12.9

[1] Derived from Appendix E of U.S. EPA (1976).
[2] Marginal capitalized noise damages are $50 per dB(A) per household in 1975.
[3] Marginal capitalized noise damages are $150 per dB(A) per household in 1975.

the fuel savings benefits would be lost if the 80 dB(A) standard were not imposed. Additional analysis will have to be conducted before this important issue can be resolved.

OTHER BENEFIT-COST ANALYSES

The results of the preceding illustrative benefit-cost analyses are not intended to constitute definitive guides to policy. The steps of cost-benefit analysis are not a cut-and-dried matter over which there is universal agreement; much depends on the judgment of the analyst. There is a scant, but growing, literature of benefit-cost analyses of transportation noise abatement; nearly all of it deals with aircraft noise. Three studies that examine the issues covered here are those by the Council on Wage and Price Stability (COWPS) (1975a), Safeer (1975), and Federal Aviation Administration (1976). We offer some comments on the relation of the results of those studies to those reported by Nelson (1975).

The COWPS study compared the benefits and costs of a SAM8D/3D retrofitting program that involves the installation of sound absorption materials (SAM) in the engine nacelles of most existing commercial jets

TABLE 9.11 Net Benefits of Truck Noise Abatement, 1977-2000 (Billions of 1975 Dollars)

Abatement Program	Net Benefit Equals:[1]			
	(6)-(4)	(9)-(4)	(10)-(4)	(10)-(5)
	At a 4% Real Discount Rate Until the Year 2000			
Baseline	–	$ 0.8	$ 2.5	$ 2.5
1 - 83 dBA	$11.3	12.1	13.8	13.6
2 - 83/80	9.0	10.3	12.9	12.3
3 - 83/78	5.8	7.2	9.9	9.4
4 - 83/80/75	(0.3)	1.3	4.6	4.1
	At an 8% Real Discount Rate Until the Year 2000			
Baseline	–	$ 0.5	$ 1.7	$ 1.7
1 - 83 dBA	$ 7.4	7.9	8.9	8.8
2 - 83/80	5.5	6.3	7.8	7.4
3 - 83/78	3.8	4.6	6.2	5.9
4 - 83/80/75	0.3	1.3	3.2	2.9

[1] Cost and benefit totals obtained from Tables 9.9 and 9.10, respectively.

using Pratt and Whitney JT8D and JT3D engines. The benefits were calculated on the assumption that a two-segment (6°/3°) landing procedure (TSL) had already been instituted for all commercial aircraft, thereby reducing noise exposure, particularly outside the NEF-40 contour. The report states:

> By extrapolating from the EPA data, we were able to determine that if nothing is done except to implement the proposed two-segment landing approach, approximately 5.8 million people will be living within the 30 NEF or higher noise contours by 1978. Retrofitting the entire non-Part 36 fleet by 1978 would result in a 2 to 3 NEF dB reduction in noise exposure for these people as compared to the exposure they would otherwise experience. Assuming an average of three persons per household, an average 1973 property value per household of $21,300, and using the consensus estimate of 0.5 percent property value loss per NEF dB, the marginal benefit of retrofit would be a maximum of $617.6-$832.41 million. Since EPA estimates the cost in 1973 dollars of retrofitting with quiet nacelles to be $800 million, the benefit-cost ratio is 0.772 (COWPS 1975a:10-11).

Several questions can be raised. The noise depreciation figure used in the COWPS study is $105 per NEF, which, in light of the research reviewed in Chapter 7, falls well toward the lower range of the available noise damage estimates. Had an intermediate figure of $140 per NEF been used instead, i.e., a 0.7 percent discount, the retrofitting program would have passed the benefit-cost test used in the COWPS study. (It would have yielded a benefit figure of $821.4 million, as compared with the $800 million estimated cost.) Nelson's calculation used the higher $140 figure and assumed retrofitting of the fleet would be completed by 1978 (as does the COWPS study); in addition, he examined the option of retrofitting without the adoption of TSL. One would then naturally expect Nelson's assessment of benefits to exceed those of the COWPS. Yet they are smaller; they amount to $567.5 million while the COWPS figure is $617.6 million.

The difference in the results of the calculation lies in the estimated size of the population exposed to noise levels equal to NEF 30+. Nelson used 5.12 million as the estimate of the number exposed in 1975, whereas the COWPS used the estimate of 6.2 million for 1972 (Safeer 1975:1). It is disturbing that three-years difference in the program evaluation date causes very substantial differences in the evaluation of benefits. The cost figures differ by much less; they total $800 million in the COWPS study, whose evaluation point is 1972, and $611 million in the Nelson study, with its 1975 evaluation point. The major realm of contention is the benefit side. It seems clear that the data as well as the admissible class of hypotheses regarding the shape and magnitude of the benefits stream are uncertain.

Much hinges on the cost effectiveness of a two-stage landing procedure in reducing noise. In virtually every cost-effectiveness study, TSL is judged the first option that ought to be adopted. (See Safeer 1975, and Muskin and Sorrentino 1976.)

But two-segment landings have, in fact, been ruled out of consideration by the FAA for reasons of safety. The same issues of cost effectiveness, however, apply to alternative operational techniques for abating aircraft noise, such as reduced flap/reduced thrust approaches or local flow control.

This observation also raises serious questions about the acceptability of the available evaluations of the SAM retrofitting option, which, as already noted, has always been assumed to be undertaken after the adoption of TSL procedures. Clearly, such an assumption attributes lower benefits to a SAM retrofitting program than it would yield if it were adopted alone.

CONCLUSION

The reader hoping to find here a clear statement about the desirability of any particular noise abatement program will be disappointed by this report. Generally, the calculations are too close to permit an unqualified judgment, since comparatively minor changes in assumptions or estimates can make the difference between passing and failing the benefit-cost test. That conclusion in itself is important for it must undermine the extreme positions that have been taken on this issue.

Although benefit-cost analysis does not yield an unequivocal result for every program, the procedure can yield more conclusive evaluations of some noise abatement options. For example, some programs seem to pass the benefit-cost tests unequivocally. A program of modified operational procedures for aircraft arrivals and landings, such as local flow control, is one. Local flow control refers to procedures by which an airplane starts its landing at a considerable distance from the airport—as much as 100 miles away. The airplane begins a long, slow continuous descent and lands under low power and reduced flap settings rather than approaching the airport under normal speed, circling, and then landing under higher thrust and more extensive wing flap use. The costs of this program are minimal, and there are several benefits. The obvious ones are a reduction in noise, a reduction in exhaust emissions, and a saving in fuel. Indirectly, there are savings in time, and the reduction in air traffic and congestion allow take-off procedures to proceed more smoothly and also save fuel, time, and emissions. In fact, under most sets of assumptions, the costs of the program are negative.

It is important to reemphasize the Committee's view that the result of a cost-benefit analysis is but one piece of evidence to be considered in arriving at a policy decision. Even where imperfections of data or of method do not permit a definitive cost-benefit calculation, policy decisions do have to be made. Failure to determine a policy is itself a decision, albeit one that is in many cases difficult to justify. We believe that wherever feasible, a cost-benefit calculation should be carried out because it can contribute to the rationality of the decision process. But its results should never be used as a mechanical decision rule, both because of the imperfections of the calculations and because they do not encompass all of the relevant considerations. But the decision maker will still have to confront the issues, and they will have to formulate programs on the basis of evaluations of the nonquantifiable benefits and the other pertinent considerations that we have emphasized in earlier chapters.

Finally, we must note that we consider it unfortunate that the debate over aircraft noise reduction has centered on a narrow class of technological options, such as those examined in our illustrative calculations, when it is clear that there is an extensive set of alternative programs that can provide substantial noise abatement, perhaps more effectively and more efficiently than those usually considered. Among the alternative methods available to reduce aircraft noise to an amount equivalent to the FAR-36 are noise emission charges; noise quotas that may be set at each airport, for each carrier's fleet, or for the entire civil aircraft fleet; a surcharge on B-707/DC-8 flight tickets; or a court ruling that makes airport authorities liable for an average one-time compensation of $150 per NEF for each residence exposed to NEF 30+ by the year 1978 or 1980.[4]

Until recently, airlines and airport authorities have operated under conditions that offered them the environs of airports as free dumping grounds for the disposal of noise, and they have responded to this condition with vigor and resourcefulness. But noise disposal is not a free good—for noise does produce substantial harm. Of course, noise abatement is also a costly process, and that is why we cannot afford a noise free environment. Yet society can ill afford to permit noise to grow unchecked or, at least in some cases, even to continue at its present levels.

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[4] It should be noted that if such penalties are announced well before the date at which they will become effective, it will give time for airport authorities and airlines to undertake the appropriate noise reduction measures, whereas if the penalty is instituted without notice, it will merely constitute a once-and-for-all-time transfer from airlines and airport authorities to homeowners. Such a transfer provides no incentive for noise reduction and is also inequitable since many current homeowners whose properties lie within an NEF-30 contour have already been compensated for the noise damage they suffer through the discount in the value of their property, when they purchased their residence, compared to property in quieter areas.

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